Metro New York Evacuation Project

Metro New York Transportation Agencies

Hurricane Evacuation Study

Facilities Update and Evacuation Decision Tools

TECHNICAL DATA REPORT

Final Report

Completed September 2011

US Army Corps of Engineers®

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION U.S. DEPARTMENT OF COMMERCE NOAA

OEM New York City Office of Emergency Management

Metro New York Transportation Agencies

Hurricane Evacuation Study

Facilities Update and Evacuation Decision Tools

Technical Data Report

Final Report

Submitted to:

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and

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Submitted by:

Atkins

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List of Acronyms

ARC	American Red Cross
ASCE	American Society of Civil Engineers
ATM	Abbreviated Transportation Model
DES	Department of Emergency Services
DoD	Department of Defense
DVD	Digital Video Disc
FEMA	Federal Emergency Management Agency
GIS	Geographic Information System
HES	Hurricane Evacuation Study
HURREVAC	HURRicane EVACuation Tracking and Analysis Software
MEOW	Maximum Envelope of Water (from SLOSH Program)
MOM	Maximum of Maximum (from SLOSH Program)
MSL	Mean Sea Level
NAVD88	North American Vertical Datum
NGS	National Geodetic Survey
NGVD29	National Geodetic Vertical Datum
NHC	National Hurricane Center
NHP	National Hurricane Program
NJOEM	New Jersey Office of Emergency Management
NJOHSP	New Jersey Office of Homeland Security and Preparedness
NOAA	National Oceanographic and Atmospheric Administration
NWS	National Weather Service
NY1	New York basin SLOSH run (first iteration)
NY2	New York basin SLOSH run (second iteration)
NY3	New York basin SLOSH run (third iteration)
NYCOEM	New York City Office of Emergency Management
NYSDHSES	New York State Division of Homeland Security and Emergency Services
NY-NJ-CT-PA RCPT	New York, New Jersey, Connecticut, Pennsylvania Regional Catastrophic Planning Team
NYSOEM	New York State Office of Emergency Management
RELT	Regional Emergency Liaison Team
SLOSH	Sea, Lake and Overland Surges from Hurricanes
SS HW Scale	Saffir-Simpson Hurricane Wind Scale
TDR	Technical Data Report
TS	Tropical Storm
USACE	United States Army Corps of Engineers
USACE - NAN	United States Army Corps of Engineers - New York District
VERTCON	Computer program that finds the differences between NAVD88 and NGVD29

1.0 Introduction

This Technical Data Report (TDR) documents the major activities and findings of the Metro New York Transportation Agencies Hurricane Evacuation Study Facilities Update and Evacuation Decision Tools project (Metro NY Evacuation Project), initiated by the United States Army Corps of Engineers, New York District (USACE-NAN) and the New York City Office of Emergency Management (NYCOEM) in October 2009. Pursuant to the project scope of work, the project contractor, Atkins, coordinated closely with the NYCOEM and the Regional Catastrophic Planning Team (RCPT) to update and expand data contained in the *Metro New York Hurricane Transportation Study TDR* (1995) as well as develop hurricane evacuation decision making tools. These tools include an updated Critical Facilities Decision Making Tool in Hurrevac2010, a new Risk Profile Tool in Hurrevac2010, a prototype of an Evacuation Dashboard, and a working draft Regional Emergency Liaison Team (RELT) Plan.

1.1 Background and Purpose

In the 16 years that have elapsed since the *Metro New York Hurricane Transportation Study TDR* (1995) was published, a range of improvements in understanding regional vulnerabilities has emerged, including new demographic and roadway characteristic data and evacuation clearance times from more recent regional evacuation studies, which were compiled in the *New York State Hurricane Evacuation Restudy TDR* (2009) and the *New Jersey TDR* (2010). Subsequent to these studies, an updated Sea, Lake and Overland Surges from Hurricanes (SLOSH) model run for the New York Basin was conducted in 2010. These new model runs take advantage of enhancements the National Oceanic and Atmospheric Administration–National Weather Service (NOAA-NWS) has made to the modeling approach to improve the accuracy of storm surge predictions. In addition, transportation agency priorities regarding which facilities should be studied have expanded considerably reflecting new facilities built since 1995 and an expanded list of locations. Further, the previous version of HURREVAC, which included the original facilities list, was greatly enhanced in 2010. The purpose of this project is to recognize and identify these changing conditions by leveraging best available data and methods to develop tools for better understanding the transportation network's vulnerability to a coastal storm in the metropolitan region of New York City.

The Metro NY Evacuation Project provides New York metropolitan area emergency managers and transportation providers with the tools and documentation necessary to effectively communicate facility vulnerability information to its regional partners and to provide objective criteria to assist with difficult-to-make evacuation decisions. The intent of this TDR is to document the details regarding how the project data was developed to describe the process and results of each task; and support the results with easy to understand maps, diagrams, and tables. The TDR is available as a hard copy report as well as in an interactive DVD format to facilitate user access to the data, as well as the distribution of these project findings.

The work order for this project was executed in November 2009. The services provided by the contractor included the preparation of various deliverables and supporting documentation. Work was undertaken in close coordination with the USACE-NAN and NYCOEM. Multiple stakeholder meetings were held to ensure that the regional stakeholders had input into the project effort and were informed of its progress. The primary deliverables included:

Deliverable 1: *Verification and Updating of Agency Facility Critical Elevations and Vulnerabilities* – Coordinate with regional agency staff through the USACE-NAN and NYCOEM to assess the regional evacuation network. Identify vulnerability changes to the facilities included in the previous study, include new vulnerability locations, obtain best available elevation data for all facilities, and collect facility timing requirements.

Deliverable 2: *Application of new SLOSH Model Surge Elevations to the evacuation system and facility entrances* – Utilizing recently developed New York SLOSH basin data, third iteration (NY3), assess facility flood vulnerabilities by comparing expected inundation levels to best available facility elevations. An assessment of increased wind vulnerability will also be made for non-flood prone high-level structures.

Deliverable 3: *Evacuation Decision Making Facilities Tool* in Hurrevac2010 – Update and expand the Metro New York facilities tool currently included in HURREVAC. This includes updating the timing parameters for transportation agency facilities, improve the user interface of the tool, and coordinate with Sea Island Software (SIS) for integration into Hurrevac2010.

Deliverable 4: *Hurricane risk profile in Hurrevac2010* – Develop a hurricane risk profile to be included as an integrated, but stand alone, module to Hurrevac2010. This tool allows decision makers to identify the local risk from an approaching tropical storm and develop appropriate preparedness actions.

Deliverable 5: *Critical Evacuation Facilities Dashboard* – Design, develop, test and launch a user-friendly prototype dashboard that integrates critical data from the evacuation decision-making facilities tool into a single computer based display within HURREVAC.

Deliverable 6: *RELT Plan and Executive Checklists* – Review existing documents and develop a working draft RELT Plan that incorporates recommended modifications. The plan includes a regional decision making coordination framework, as well as executive and operational decision-making checklists.

1.2 Authority / Funding

This project was initiated under the direction of the USACE-NAN, at the request of the NYCOEM. The project was funded by NYCOEM through the USACE Interagency and International Services (IIS) program. The IIS program provides assistance to non-Department of Defense (DoD) agencies, including state and local governments, to supplement these agencies' technical resources. USACE provides IIS program support under the authority of the Economy in Government Act [31 U.S.C. 1535].

1.3 Project Area

The project area consists of all the boroughs of New York City and surrounding counties that are considered to be part of Metropolitan New York City. This area includes the boroughs of Manhattan, Brooklyn, Queens, the Bronx, and Staten Island in New York City; Dutchess, Putnam, Rockland, Westchester, Nassau and Suffolk Counties in New York; Passaic, Bergen, Essex, Hudson, Union, Middlesex and Monmouth Counties in New Jersey; and Fairfield County in Connecticut. These counties correspond to the project area extent that was included in the *Metro New York Hurricane Transportation Study TDR* (1995). The project area and surrounding region are shown in Figure 1.

1.4 Project Management / Coordination

The contractor provided overall management for the Metro NY Evacuation Project in close coordination with NYCOEM and USACE. Contractor staff supported several on-site stakeholder and project team meetings.

1.5 Project Meetings / Workshops

The principle stakeholder meetings included:

- Project Kickoff Meeting, December 14, 2009
- Project Status Meeting, March 5, 2010
- Risk Profile Coordination Meeting, July 13, 2010
- Stakeholder Workshop, July 14, 2010
- Dashboard Workshop, November 18, 2010
- Hurrevac2010 Training Workshop, April 13 and 14, 2011

Meeting materials prepared are included in Appendices A through H. Each agency that had representation at the initial kickoff meeting can be found in Appendix A. Each of these agencies was then invited to attend and provide feedback at the follow up sessions.

In addition to these meetings, the staff of NYCOEM hosted bi-weekly conference calls throughout the term of the project with the USACE-NAN and contractors to discuss and resolve emerging issues.

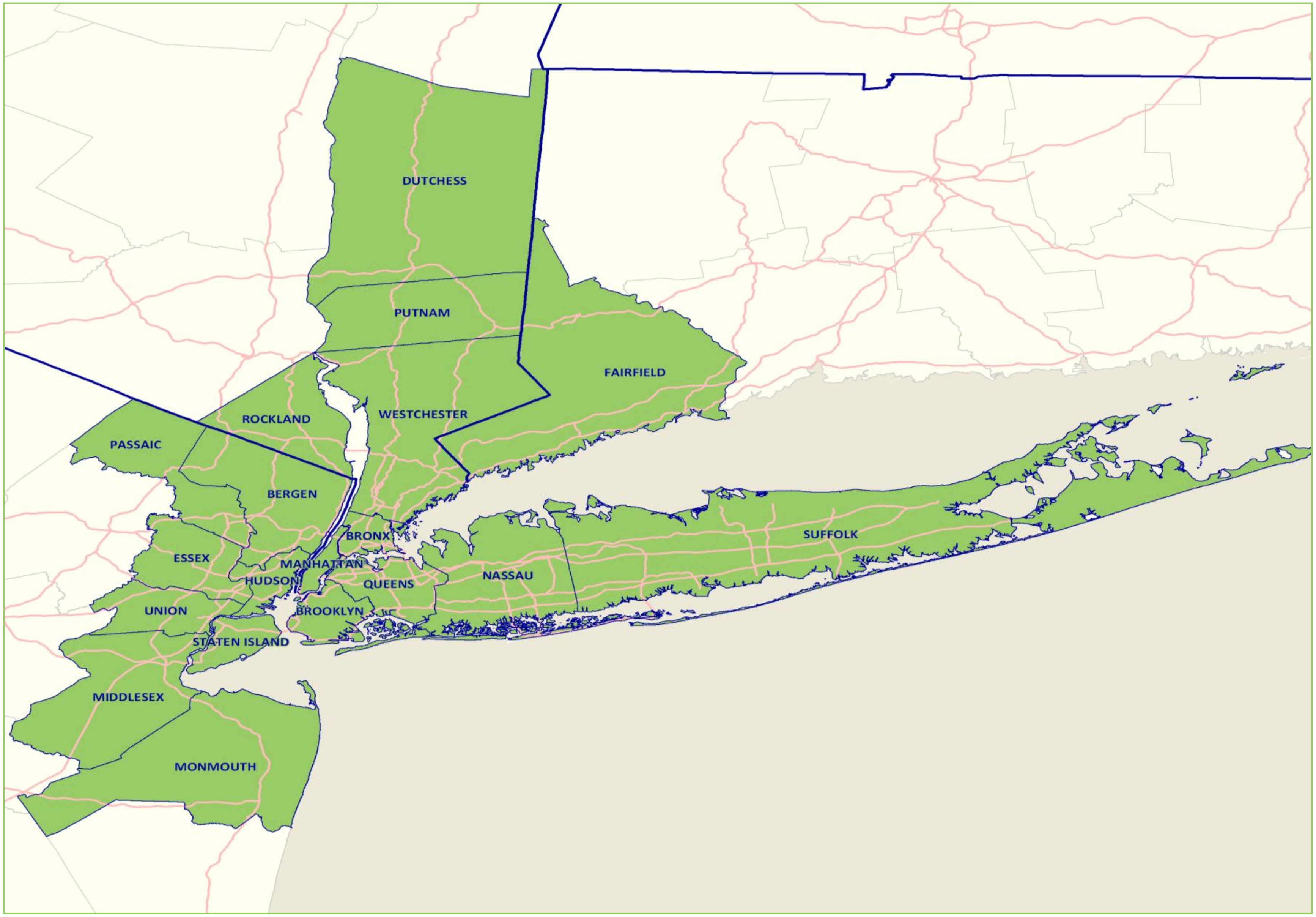

Figure 1: Project Area Map

2.0 Previous Hurricane Evacuation Study Efforts

This project builds on a series of Hurricane Evacuation Studies (HESs) and related analyses that have been conducted in the Metro New York region over the past 20 years. In 1990, the NHP sponsored HESs for New York, New Jersey, and Connecticut. The objective of those initial studies was to determine areas subject to storm surge inundation, the number of residents at risk to hurricane surge and wind, and the time required to evacuate those individuals to safe locations. The first study directly related to the region was the *New York State Hurricane Evacuation Study TDR* (1993). This section provides an important understanding of the context in which the current project is being undertaken as well as the reason why an update was essential.

2.1 Metro New York Hurricane Transportation Study TDR (1995)

As the initial New York State and New Jersey State HESs were underway, federal, state, and local emergency managers identified a gap in the analysis regarding potential storm impacts to the regional evacuation roadway network and supporting infrastructure. After several years of active stakeholder coordination, this study was undertaken to support regional planning objectives. This study assessed the potential impacts of hurricanes and other severe coastal storms on the infrastructure of the Metro New York transportation network and provided data to support the development of multiple transportation agencies' preparedness plans. The primary objectives of the this study were to identify the potential wind and surge hazards to the facilities and users of each major metropolitan transportation system; to determine the vulnerability of those facilities to wind and surge hazards and recommend mitigation measures; identify offices with decision making responsibility related to coastal storm threats; recommend decision-making and coordinative procedures; and to formulate specific response actions to be taken by transportation agencies in coordination with state and local governments.

2.2 Key Findings from the Metro New York Hurricane Transportation Study TDR (1995)

The key finding of the *Metro New York Hurricane Transportation Study TDR* (1995) included:

- Coastal storms that would present moderate hazards in other regions of the country could result in heavy loss of life and disastrous disruptions to communication and travel in the Metro New York Area.
- Depending upon the intensity, approach direction, and forward speed of a land-falling hurricane in Metro New York, a storm surge of up to 30 feet above normal tide level could be generated in some locations.
- When potential storm surge heights are compared to critical tunnel entrance elevations, as low as 7 feet above mean sea level, the vulnerability of underground mass transit is

apparent. The December 1992 extra-tropical storm (nor'easter) was a "wake-up call" highlighting this vulnerability.

- As a hurricane approaches, the rate-of-rise of storm surge could increase quite dramatically. With a Category 3 hurricane, flood depths in the Metro area could rise as quickly as 12 feet per hour. Emergency management officials must anticipate, rather than react to, this hazard for an effective hurricane emergency response.
- Extreme winds associated with an approaching hurricane will have major impacts on the operation of high-level bridges and high-rise buildings. For a Category 3 hurricane, sustained tropical storm winds may arrive on the surface 3 ½ hours before the peak winds, but at heights of 150 to 200 feet, those winds could arrive 6 hours earlier.
- Heavy rainfall preceding higher hurricane landfall and gusts could severely affect critical mass transit and highway movement, particularly in northern New Jersey areas that are subject to riverine flooding.
- Due to the varying degrees of vulnerability of seaports, bridges, airports, mass transit, and highway facilities to storm surge, wind and rainfall, their closure is expected to occur at different times. The study recognized that for a Category 3 hurricane directly affecting the area, the seaports and high-level bridges will probably be the first to close. The airports and lower-level bridges would be next to cease operation, with remaining surface and tunnel transportation closing last.
- Mitigation measures to reduce potential loss of life and property will be important. A timely decision to curtail or close government, schools, and private businesses before a storm arrives would greatly reduce the demand for evacuation and sheltering resources. Coordinated, early decision making among governmental and transportation agencies will help ensure the success of hurricane response.

2.3 Additional Study Efforts

In the late 1990s through the late 2000s, the NHP sponsored a series of studies constituting the New York State Hurricane Evacuation Restudy. In addition to reassessing the hazards and updating the evacuation clearance times included in the *New York State Hurricane Evacuation Study TDR* (1993), these studies developed methods for estimating and managing a mass transit evacuation with a high public sheltering component. The study also included the development of an abbreviated transportation model, or ATM, to allow emergency managers to easily review and adjust modeling data, update inputs and test alternate scenarios.

A final capstone study, the *New York State Hurricane Evacuation Restudy Technical Data Report* (2009) catalogued the multi-year study effort and thoroughly identified the hurricane vulnerability, public behavior, and response timing parameters associated with potential hurricanes in the New York area. The TDR was made available in multiple mediums, including full print and interactive DVD for ease of use.

Table 1 provides a listing of reports related to the Metro New York project area.

Table 1: Previous Study Efforts

Date	Title
1987	NY1 - New York Basin SLOSH Model Run (first iteration)
1992	New Jersey Hurricane Evacuation Study
1993	New York State Hurricane Evacuation Study Technical Data Report
1995	Metro New York Hurricane Transportation Study – Project Findings
1995	Metro New York Hurricane Transportation Study – Technical Data Report
2000	NY2 - New York Basin SLOSH Model Run (second iteration)
2007	New Jersey Hurricane Evacuation Study Transportation Analysis
2009	New York State Hurricane Evacuation Restudy Technical Data Report (for New York City, Nassau, Suffolk, and Westchester Counties)
2010	New Jersey Technical Data Report
2010	NY3 - New York Basin SLOSH Model Run (third iteration)

The current project, the Metro NY Evacuation Project, updates the *Metro New York Hurricane Transportation Study TDR* (1995). Just as the 1995 work efforts augmented and expanded upon the original 1993 work, this effort expands upon the transportation analysis performed for the *New York State Hurricane Evacuation Restudy TDR* (2009) and has been formatted to serve as an appendix to that report.

3.0 Transportation Agency Facility Data Collection and Updates

The New York metropolitan area has an elaborate, multi-modal transportation system that includes roads, rail, rail yards, ferries, marinas, bridges, tunnels and airports that may be used to support evacuations. For decision-makers to make appropriate evacuation decisions, an understanding of the vulnerabilities and capabilities of the transportation network is essential. Over the past 15 years since the initial data was collected, infrastructure improvements and changes to the transportation network have occurred. Additionally, the completion of the *New York State Hurricane Evacuation Restudy TDR* (2009) and updated SLOSH vulnerability data all provided an opportunity to revisit data on transportation facilities.

The Transportation Facility Data are the backbone of this project and inform most of the other project deliverables, including informing the HURREVAC Evacuation Decision-making Facilities Tool and the Critical Evacuation Facilities Dashboard. The facility data was compiled into a spreadsheet often referred to as the Master Facilities List in this report. Appendix I contains a reduced listing of the Master Facilities List that has been scaled down based on input from NYCOEM. Appendix J contains the HURREVAC selected facilities.

3.1 Background

The *Metro New York Hurricane Transportation Study TDR* (1995) focused on the flood and wind vulnerabilities of 172 facility locations in the Metro New York region. Detailed field reviews by the USACE included surveys of elevations at established critical system entry points for storm surge. Reviews of historical as-built drawings for roadway and transit tunnel facilities revealed the interconnectivity of agency facilities and their common vulnerability. Documented impacts from Hurricane Gloria and the December 1992 nor'easter highlighted the fact that the region faces a real threat from hurricane storm surge and winds. Some of the previous study key findings regarding facility attributes and vulnerability include:

- *Unique Storm Surge Vulnerability* – System entry points are well below 10 feet in many locations and once underground tunnels begin to fill with water, damage to infrastructure and the threat to system users will be enormous.
- *High Storm Surge Values* – For even moderate hurricanes, the levels of storm surge generated in the project area are quite high due to the funneling affects of the right angle formed by the New Jersey and New York/Long Island land masses, commonly referred to as the NY Bight.
- *Quick Rate of Water Rise* – The SLOSH model and hydrograph data from Hurricane Gloria at the Battery show that surge water can rise as much as 10 to 17 feet per hour requiring a proactive approach to emergency preparation and response, versus a reactive approach.

- *Early Tropical Storm and Hurricane Force Wind Arrival* – Due to the elevations of critical bridge facilities and tall buildings, dangerous winds will arrive several hours before they are experienced at ground level.

The previous study set forth a concept of different time components for transportation agencies based upon their individual and collective need to mobilize and make decisions; accommodate evacuee travel movements; close and secure facilities; and anticipate surge and wind hazards. This new Metro New York Evacuation project seeks to refine and update those time components. While specific hourly numbers are included based on best available data and professional judgments, it should be recognized that actual event time sequences will unfold very quickly and actual experience will vary depending on the unique storm meteorology, track, and public behavior.

3.2 Overall Methodology

The process for completing the critical facilities plug-in occurred in three major phases. Each is described in detail below:

Phase 1: Data Collection – The framework for the data to be assembled was developed in coordination with NYCOEM and the agency stakeholders. The data fields and facilities employed in the previous study and the original HURREVAC tool were used as a starting point, with a number of additional data fields added. NYCOEM provided the basic data request directly to the transportation agency stakeholders. Stakeholders were given ample time to research and provide the requested information to the project team. Much of the data requested was simply descriptive; including information such as the owner, name, elevation and location of each facility. Agencies were also asked to provide evacuation time phase estimates for mobilization/decision making and shutdown/closure for each facility. NYCOEM spent a significant amount of time coordinating directly with each agency to obtain the required data.

Phase 2: Data Augmentation and Calculations – After the initial data was obtained from the stakeholder agencies, gaps in the basic data set were filled in by the project team. In addition to the several data fields that were added directly by the project team, some agencies provided additional facilities to include in the data collection. One such example of this is the addition of the bus depot locations added by the NYCT. Some of the additional data fields included basic information, such as facility type and primary hazard type. Data from secondary sources, such as the clearance times from the *New York State Hurricane Evacuation Restudy TDR* (2009) and the surge elevation from the NY3 SLOSH model were also added. The NY3 is the third iteration of SLOSH runs for the New York District, completed in 2010. Other data fields, including but not limited to elevation conversions from the National Geodetic Vertical Datum of 1929 (NGVD29) to North American Vertical Datum of 1988 (NAVD88), and the estimation of pre-landfall time, were calculated by the project team.

Phase 3: Agency Verification and Acceptance – As a final check on the data, the agencies were provided with an opportunity to review and edit the Master Facilities List assembled by the project team. The data returned to the stakeholders for review included explanatory notes specific to individual facilities. The review process allowed agencies to re-confirm the locations and facility data they provided, to add facility-specific notes, and to affirm data augmented or calculated by the project team. Agency edits and comments were addressed and the revised Master Facilities List was circulated for final acceptance. A subset of the Master Facilities List was developed to be used as the Hurrevac2010 facilities list.

3.3 Agency Involvement

As noted, NYCOEM staff assembled facility data from regional transportation agencies. These agencies were assumed to provide "best available data" which in some cases may have involved professionally informed estimates or regional averages. The following transportation agencies provided data for the Master Facilities List:

- AMTRAK
- Individual jurisdictions on Long Island [Long Island Jurisdiction (LI JURIS)]
- Long Island Private Ferry Operators (LI FERRY)
- Metropolitan Transportation Authority Bridges and Tunnels (MTA BT)
- Metropolitan Transportation Authority Long Island Railroad (MTA LIRR)
- Metropolitan Transportation Authority Metro-North Railroad (MTA MNR)
- Metropolitan Transportation Authority New York City Transit (MTA NYCT)
- Nassau County (NACO)
- Nassau County Bridge Authority (NACOBA)
- New Jersey Department of Transportation (NJDOT)
- New Jersey Transit (NJT)
- New York City Department of Transportation (NYCDOT)
- New York State Department of Transportation Region 8 (NYSDOT8)
- New York State Department of Transportation Region 10 (NYSDOT10)
- New York State Department of Transportation Region 11 (NYSDOT11)
- New York State Thruway Authority (NYSTA)
- Port Authority of New York and New Jersey (PANYNJ)
- Suffolk County (SUFFCO)
- Westchester County (WESTCO)

NYSDOT10 provided the data for the jurisdictions and agencies on Long Island.

3.4 Data Fields

3.4.1 Agency Provided Data

Agencies were asked to provide data for the following fields as shown in Table 2.

Table 2: Agency Provided Data

Data Component	Description
Facility Name	Full name of critical facility and qualitative description of specific point where elevation was taken
Elevation	Elevation of most vulnerable location at critical facility, including datum and metadata. The location was chosen as the facility's lowest point that when exposed to a coastal storm hazard would render the facility inoperable during an evacuation. (Original data from *Metro New York Hurricane Transportation Study TDR* (1995) if provided at the time was in NGVD29)
Mobilization/Decision Making Times	The time (in hours) needed for agencies to take administrative and operational actions required to support an evacuation
Shutdown/Closure Times	The time (in hours) needed to clear transportation system users and to secure facilities, personnel, and equipment before the arrival of tropical storm force winds
Spatial Data (Latitude/Longitude)	Latitude and longitude coordinates for critical elevation location at facility
Other Notes	Any additional information to support data including wind vulnerabilities, special characteristics for closing facilities, etc.
Facility Owner Agency Name	NYCOEM assigned a full name for each primary owner/operating agency for each facility

3.4.2 Supporting Data Fields, Calculated Data and Augmented Data

The project team added the following supporting data fields as shown in Table 3.

Table 3: Project Team Added Data

Data Component	Description
Facility Type	The primary type of transportation facility. For each facility location, one of eleven types is indicated: • A - airport • BD - bus depot • F - ferry • HB - highway bridge • HS - highway surface • HT - highway tunnel • P - port • R - rail • RS - rail station • RT - rail tunnel • RY - rail yard
Primary Coastal Storm Hazard	The coastal storm hazard (Surge or Wind) that will compromise the use of that facility first.
Worst Case 2010 SLOSH Surge Elevations at High Tide in feet NAVD88	From NY3 for Categories 1-4.
Depth of Flooding by Category of Storm in feet NAVD88	Calculated by subtracting the critical land elevation from the 2010 worst case surge elevations at high tide for Categories 1-4.
Change in Slosh Surge Elevation for 1987 SLOSH Model to 2010 SLOSH Model in feet NAVD88	Calculated by subtracting the 1987 SLOSH surge values in the *Metro New York Hurricane Transportation Study TDR* (1995) from the new 2010 SLOSH surge model values for Categories 1-4.
Clearance Times	Determined detailed facility clearance times from internal HES modeling archives for Categories 1-4.
Pre-Landfall Hazard Times	The pre-landfall hazards time is the time prior to eye landfall that a facility may be at risk of high winds or flooding for Categories 1-4.
1987 SLOSH Surge Elevations from 1995 work effort in feet NGVD29	Category 1-4 worst case surge elevations for this location from the *Metro New York Hurricane Transportation Study TDR* (1995); facilities with an 'NA' were not included in the original study effort.
1987 SLOSH Surge Elevations from 1995 work effort in feet NAVD88	1987 SLOSH surge values converted to NAVD88 by subtracting NOAA conversion factor from NGVD29 values for Categories 1-4.
In feet NGVD29 to NAVD88 NOAA Conversion Factor	Used NGS/NOAA VERTCON to convert data collected in the NGVD29 datum to NAVD88 using the latitude, longitude, and elevation (as provided by the agencies).

3.4.3 Discussion of Specific Data Fields

Latitude and Longitude Coordinates

In order to accurately evaluate each facility location for its surge impacts it was necessary to find and verify geographic coordinates. Some of the initial latitude and longitude data was provided by NYCOEM staff in coordination with transportation agency staff. For facilities where latitude and longitude coordinates were not provided, the project team used a multi-step review process to collect data and ensure accuracy. The coordinates were determined by using the facility name and locating the site on http://www.itouchmap.com. Each site was then re-checked for verification purposes using both www.bing.com and Delorme Xmap Professional.

Critical Facility Elevations

Some of the critical elevations that were collected in 1995 were in NGVD29, and needed to be converted to NAVD88 to compare to the new SLOSH model results. To do this conversion, the project team followed a detailed process. The National Geodetic Survey (NGS)/NOAA VERTCON website (http://www.ngs.noaa.gov/cgi-bin/VERTCON/vert_con.prl) was used to obtain the conversion factor for each location that had prior elevation data. To obtain the NAVD88 elevation, the conversion factor, approximately 1.1 feet, was subtracted from the NGVD29 referenced elevation. All elevations are referenced in feet above NAVD88.

Worst Case 2010 SLOSH Surge Elevations at High Tide

Using the 2010 SLOSH model display program developed by the National Hurricane Center (NHC) for the NY3, the highest surge value for any direction and forward speed for each category of hurricane was obtained from the values in the SLOSH Maximum of Maximum (MOM) inundation extents. The process involved selecting the latitude and longitude for each facility location, verifying the SLOSH grid location on an aerial map, and then reviewing each of the SLOSH values from the multiple SLOSH runs conducted for that grid cell. The highest storm surge elevation in feet above NAVD88 was then entered into the Master Facility List (See Appendix K) for the appropriate storm category and facility location. For those grid cells and corresponding facility locations that do not have surge flooding for a given category of storm were denoted as “dry”. Figure 2 shows an example of the process used to obtain the highest SLOSH value for any given location.

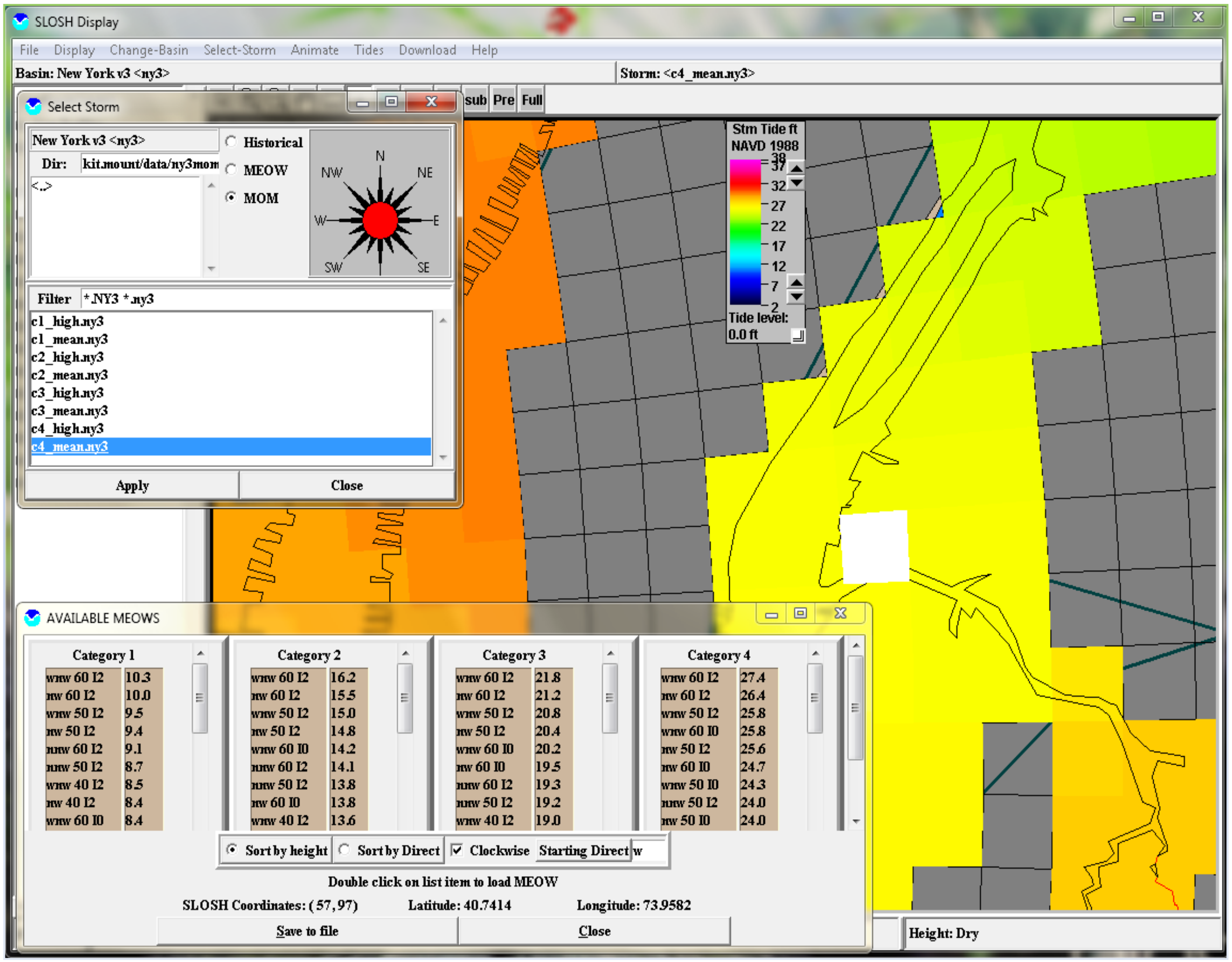

Figure 2: SLOSH Value Example (Long Island City Yard/Station, MTA LIRR)

Depth of Surge Flooding by Category of Storm

The depth of surge flooding by category of storm was determined by subtracting the average land elevation (in NAVD88 datum reference) across the grid cell from the worst case SLOSH value for each facility location listed in the Master Facilities List. A positive value indicates the number of feet of storm surge flooding that could be present at a facility location. Conversely, a negative value indicates that the land is higher than the potential storm surge and that no surge flooding is expected. It should be noted that the SLOSH model only references storm surge and not freshwater flooding that may result from rainfall in selected locations. Nor does it take into account wave heights that will also occur concurrently with the storm surge.

Change in SLOSH Surge Elevation from 1987 to 2010 SLOSH Model

A comparison of surge values from the 2010 SLOSH model to surge values provided in the *Metro New York Hurricane Transportation Study TDR* (1995), which used data from the 1987

SLOSH model, was conducted. A year 2000 SLOSH model was subsequently developed and used in the preparation of the HESs conducted in the region between 2002 and 2009.

To compare the 1987 SLOSH model results to the 2010 SLOSH model used in the current analysis, 1987 SLOSH values had to be converted from NGVD29 to NAVD88 datum. (For those facility locations that were part of the *Metro New York Hurricane Transportation Study TDR* (1995), data is included in columns of the Master Facilities List showing the original 1987 NGVD29 surge elevations and the converted 1987 SLOSH surge elevation values to NAVD88.) The 1987 SLOSH converted elevations were then subtracted from the 2010 SLOSH surge elevation values to calculate the differences between the two SLOSH models. These differences (in feet) are provided by facility location for each category of storm in the Master Facilities List. Comparisons were not calculated for the new facilities not included in the *Metro New York Hurricane Transportation Study TDR* (1995); they are identified by an N/A.

Facility Timing Requirements

In 1995, four phases of timing were determined to guide the use of transportation facilities to support an evacuation from a coastal storm. These phases of timing include requirements that transportation agencies have to mobilize their assets, support an evacuation, secure assets, and await coastal storm hazards. By taking the forecasted storm arrival time and subtracting the time needed to mobilize, clear and demobilize/close a facility, adjusting for any pre-landfall hazards, provides the evacuation decision time. This is the shortest time at which an agency can start fully utilizing a facility for evacuation purposes and still ensure that the facility can be closed down before the arrival of the forecasted hazard event. It should be noted that this block of time may overlap some of the evacuation time that is occurring in the region and that while treated as a discrete time component, it may be occurring concurrently with other preparedness activities. The approach of building in mobilization/decision making time as a discrete component adds a degree of conservatism to the evacuation projected timelines. Each phase is discussed in detail below including how it was collected or calculated.

For wind-affected facilities, HURREVAC computes the direct hit arrival time of 39 mph winds to the facility, and subtracts the combined times for mobilization/decision, clearance, shutdown/closure, and pre-landfall hazard times to arrive at a proper decision time.

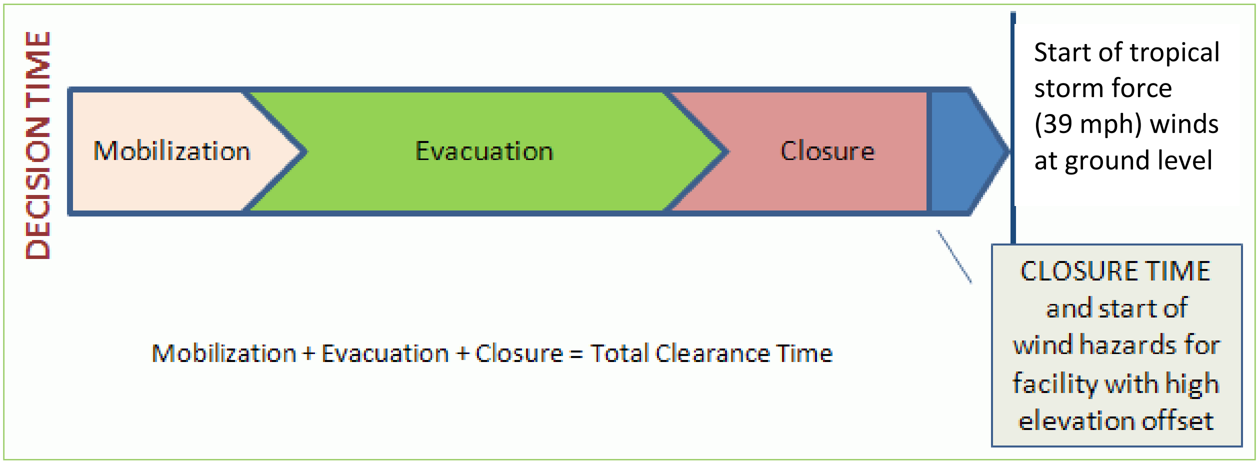

Figure 3: Determination of Wind Hazards

After the flood arrival time is determined from the SLOSH model offset, the program then subtracts the combined times for mobilization/decision, clearance, and shutdown/closure, and pre-landfall hazard times to arrive at a proper decision time.

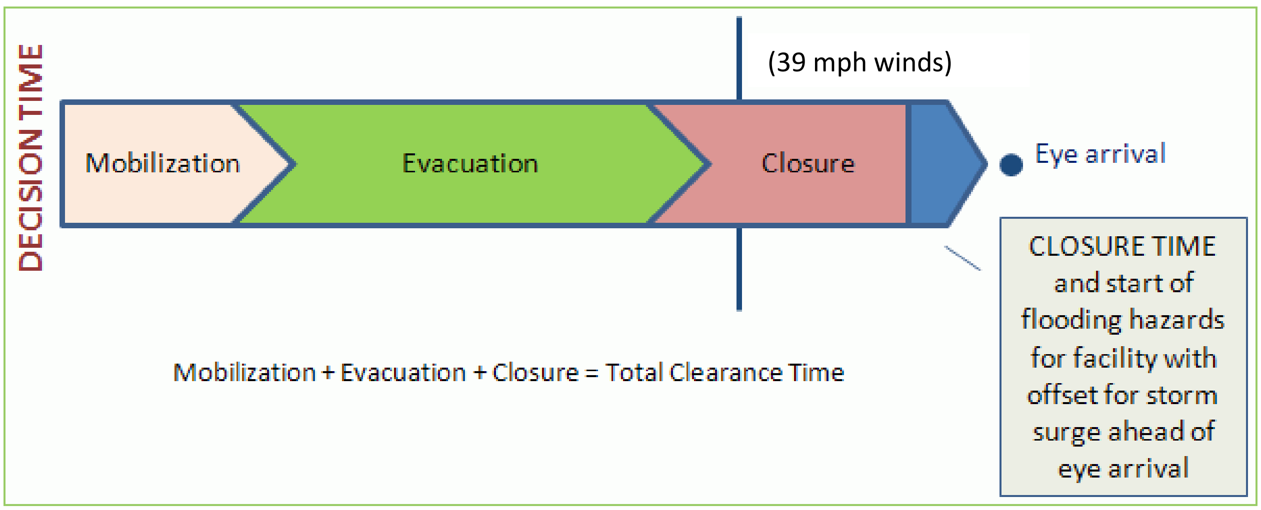

Figure 4: Determination of Flooding Hazards

Mobilization/Decision Times – Mobilization/decision times refer to the time allotted for agencies to take the administrative and operational actions required to initiate an evacuation. This block of time is associated with pulling together agency executives and emergency management staff for situational decision making and resource mobilization. This information was collected directly from stakeholders during the data collection process.

During the *Metro New York Hurricane Transportation Study TDR* (1995) development, the project team determined that the lack of experience with hurricanes in this region and the potential disruption to agency operations required additional time to weigh storm advisory data and review internal response procedures/timelines. In the *Metro New York Hurricane Transportation Study TDR* (1995), most agencies built in a three-hour block of mobilization/decision time with rail agencies and airports increasing that figure to five to eight hours. In 2010 work effort, a few of the surface roadway and bridge mobilization times were lowered by the owning agencies to one hour while most were kept to a three hour timeframe. For the airports, the PANYNJ decided to use five hours for this time component. Rail agencies included a six to eight hour time component with the exception of NJT which indicated that a fifteen minute mobilization time was sufficient.

Some locations did not have a time submitted by the agency. In this case, the time was determined by comparing the facility to facilities with similar risk characteristics. While data was developed based on professional judgment, it is important to note that all data was reviewed and accepted by the stakeholder agencies.

Clearance Times – For the purposes of the Metro NY Evacuation Project, evacuation clearance times by facility location are defined as the length of time, in hours, a facility is expected to service evacuee transportation movements.

The facility clearance times – the times that facilities are actively being used to support evacuations – were derived from the latest HESs for New York and New Jersey.

Clearance times estimated for each facility varies depending on the type of facility (transit versus highways) and location (shore exit route versus major regional inland thoroughfare). For the public transit facilities, just as in the *Metro New York Hurricane Transportation Study TDR* (1995), it was assumed that commuter rail and subway lines, in moving evacuees, would function similarly to a heavy pm peak commuter period. This period of time normally ranges from three to four hours for the bulk of commuter movements.

The modeling underlying these studies includes detailed clearance times associated with specific roadway segments. The segment-based time corresponding most closely to the physical location of each facility was used as it reflects the amount of traffic each facility will be expected to service.

The high level of background daily traffic in the region coupled with ongoing roadway construction projects can greatly complicate evacuation timing. As a measure of safety, the clearance times incorporated into the Master Facilities List reflect heavy background traffic.

It should be noted that the actual operational clearance times may be shorter than the times included in the Master Facilities List (tabular values) for a number of reasons:

- The public may not participate in the evacuation to the degree expected due to lack of hazard awareness.
- Many may choose not to evacuate surge areas due to concerns about protecting personal property and pets.
- Given the rapid approach of storms, many evacuees may wait too late to evacuate, thereby compressing the length of time that evacuee movements occur.

For the surface highways and bridges, clearance times were estimated based on segment-specific clearance times from the modeling used to develop the transportation analysis in the *New York State Hurricane Evacuation Restudy TDR* (2009) and the *New Jersey TDR* (2010). These clearance times (depending on category of storm) range from 12 hours to 33 hours for major highway facilities that carry multi-jurisdictional evacuation traffic throughout the evacuation period. For roadways and bridges closer to the Atlantic Coast whose sole function is to carry evacuee traffic off of barrier islands, times are much more moderate.

It is difficult to predict the clearance times that might be associated with the evacuation role that airports will play in the region. Airlines will tend to pull their equipment out of the region well before evacuations are complete. Many visitors and some residents will use air travel to escape the region depending on availability and cost. For clearance time, 5, 7, 10, and 14 hours respectively were included for a Category 1-4 hour hurricane event. While developed based on professional judgment, these times were vetted and approved by the owners.

Shutdown/Closure Times – Occurring sequentially after the facility clearance time once a facility is clear of users, the shutdown/closure time is the time needed to secure facilities, people, and equipment before the arrival of tropical storm force winds. Shutdown/closure times, like mobilization/decision times, were provided by agency stakeholders based on their best judgment. NYCOEM staff coordinated with transportation agency staff to review and refine shutdown/closure times incorporated in the 1995 work and to input expected shutdown/closure times for newly added facility entries.

The rail providers have a great deal of equipment and personnel that must be secured and protected before the arrival of hazardous conditions. It is imperative that the general public be cleared out of rail stations well prior to onset of hazard conditions given the system's surge flooding potential identified in the project. If surge water enters the underground rail infrastructure, the rate of rise will be very quick and lives could be endangered. This fact coupled with the tendency of the public to seek refuge from wind blown glass and debris in the underground rail stations highlights the danger involved and the importance of closing the stations in a timely manner.

For most of the rail providers, a shutdown/closure time of approximately four hours was used. For the highway facilities, bridge and tunnel owners decided on a one to two hour shutdown/closure time. Those agencies such as state departments of transportation (DOT) estimated a six hour shutdown/closure time for longer sections of freeways which would take a substantial effort to secure.

The PANYNJ estimated a five hour shutdown/closure time for the airports. The forward speed of the storm coupled with the rate at which conditions deteriorate will dictate the actual shutdown/closure time.

As with all estimates included in the Master Facilities List, any data not provided by stakeholders was developed based on similar facilities or facilities with similar risk characteristics. In all cases, stakeholders reviewed and validated all data.

Pre-Landfall Hazards Times – Hurricane decision times are based on the time it takes for the eye of the storm to reach a facility. In most cases, areas may be subject to specific hazards, such as sustained tropical storm force winds or rising water before the arrival of the eye of the storm. The pre-landfall hazards time is the time prior to eye landfall that a facility may be at risk of high winds or flooding.

Storm Surge: The *Metro New York Hurricane Transportation Study TDR* (1995) relied on 1987 SLOSH-generated time history hydrographs which were tied to approximately 100 pre-selected time history locations throughout the project area. Time history graphs show the expected rate of rise of water and were compared to a previous storm like Hurricane Gloria to give the local emergency management community confidence in the information. For the 2010 SLOSH model used in this project update, the NHC did not provide time history data.

Without the normal SLOSH time history data, a relational scale of surge arrival was created using values that were developed in the 1995 work. For each facility, the Critical Facility Elevation in feet NAVD88 was subtracted from the Worst Case 2010 SLOSH Surge Elevations feet at High Tide in feet NAVD88 to provide the Depth of Flooding by Category of Storm values in feet NAVD88.

Surge: For surge locations, the specific Depth of Flooding by Category of Storm values in feet NAVD88 for each facility were referenced to the following table to determine Pre-Landfall Hazard Time (hours). Table 4 displays the values that were used to estimate surge flooding pre-landfall hazards times for the current effort.

Table 4: Surge Flooding Pre-Landfall Hazard Times

Calculated Depth of Surge Flooding (ft) by Storm Category	Resulting Pre-Landfall Hazard Time (hours) (Surge Locations Only)
Negative (-) to 0	0
0.1 to 2.0	0.5
2.1 to 5.0	1.0
5.1 to 8.0	2.0
8.1 to 11.0	2.5
11.1 to 13.0	3.0
13.1 to 15.0	4.0
15.1 to 17.0	5.0
17.1 to 19.0	5.5
19.1 to 22.0	6.0
22.1 to 25.0	6.5
25.1 and above (+)	7.0

While this scale provides an accurate and replicable approach to estimate pre-landfall hazard given the available data, New York City officials should formally request that the NHC storm surge experts invest resources into products that would more completely support this effort and allow for future validation.

<u>Wind:</u> Regarding wind hazard, according to the American Society of Civil Engineers (ASCE) publication ASCE 7-10, "Minimum Design Loads for Buildings and Other Structures," at a height of 140 feet, design wind pressures on the Main Wind Force-Resisting System may increase by 51 percent; at 200 feet, increased by 67 percent; and at 350 feet, increased by 96 percent. The implications to tall buildings and high-level bridges are important to recognize for purposes of this project. Table 8 of the *Metro New York Hurricane Transportation Study TDR* (1995) displays the estimated arrival of tropical storm force winds at ground or surface locations and higher (150-200 feet) locations, such as elevated bridges. Specifically based on that table, the additional indicated increment of 1, 2, 2.5, and 2.5 hours respectively for Categories 1-4 storms was inserted for the high-level wind vulnerable facilities. Since the George Washington Bridge and Verrazano Narrows Bridge are at the top of the elevation range, an additional half hour was added to their increments. Wind vulnerable facilities well below 150 feet in elevation were adjusted downward by a half hour.

In an actual storm threat, HURREVAC will calculate the expected arrival of tropical storm winds at surface level in real-time and will add these additional increments to develop a pre-landfall hazards time for tropical storm winds.

3.5 Summary of Facility Data

Tables 5 and 6 provide a summary of the data contained in the Master Facilities List.

Table 5 lists facility vulnerability information for the 19 transportation agencies, sorted in the order in which they appear on the Master Facilities List. The total number of facilities, as selected by the agencies to be represented in the project through the data collection process, is provided. Facilities face a primary hazard of either surge or wind. The subset of facilities subject to each hazard is provided. Further detail is also provided on surge vulnerable facilities, with a listing of the total number of surge vulnerable facilities in each storm category provided. While facility specific data is provided in the Master Facilities List, this summary table provides an overview of the relative risk of surge or wind to facilities by agency.

Table 5: Critical Facility Summary - By Agency

Agency	Total # of Facilities	# of Surge Vulnerable Facilities				# of Wind Vulnerable Facilities	# on HURREVAC List
		Cat 1	Cat 2	Cat 3	Cat 4		
AMTRAK	10	8	9	10	10	0	2
LI JURIS	2	2	2	2	2	0	2
LI FERRY	5	0	0	0	0	5	3
MTA BT	25	17	17	17	17	8	14
MTA LIRR	21	14	16	16	16	5	10
MTA MNR	36	35	36	36	36	0	10
MTA NYCT	65	42	53	56	61	2	22
NACO	2	2	2	2	2	0	2
NACOBA	1	1	1	1	1	0	1
NJDOT	14	3	10	13	13	1	7
NJT	16	9	10	11	13	2	6
NYCDOT	14	10	10	10	10	4	10
NYSDOT8	6	0	0	0	0	6	1
NYSDOT10	13	12	12	12	12	1	9
NYSDOT11	42	19	24	28	33	9	15
NYSTA	10	9	9	9	9	1	2
PANYNJ	42	32	32	32	33	9	14
SUFFCO	1	1	1	1	1	0	1
WESTCO	2	0	0	0	0	2	1
Note: Each facility is susceptible to only one hazard (wind or surge).							

Table 6 lists the same facility vulnerability information provided in the previous table, but it is presented in reference to each jurisdiction included in the project. As a summary table, it allows each jurisdiction to see both the total number of project facilities included within their boundaries, as well as the distribution of their primary hazard risk (surge or wind).

Table 6: Critical Facility Summary – By County

Location	Total # of Facilities	# of Surge Vulnerable Facilities				# of Wind Vulnerable Facilities	# on HURREVAC List
		Cat 1	Cat 2	Cat 3	Cat 4		
New York							
Manhattan Borough	69	59	61	61	62	7	26
Brooklyn Borough	30	17	24	25	28	2	10
Queens Borough	58	33	36	43	47	10	21
Staten Island Borough	10	3	5	5	6	4	6
Bronx Borough	23	10	13	13	15	7	11
Nassau County	13	9	11	11	11	2	10
Suffolk County	23	16	16	16	16	7	15
Westchester County	33	24	24	24	24	9	7
Dutchess County	4	4	4	4	4	0	1
Putnam County	3	3	3	3	3	0	1
Rockland County	1	1	1	1	1	0	0
New Jersey							
Bergen County	13	4	9	10	12	1	7
Essex County	3	1	3	3	3	0	1
Hudson County	29	23	25	26	26	2	11
Middlesex County	4	3	3	4	4	0	1
Monmouth County	1	1	1	1	1	0	1
Passaic County	2	0	0	0	0	2	0
Union County	3	0	0	1	1	2	1
Connecticut							
Fairfield County	5	5	5	5	5	0	2
Note: Each facility is susceptible to only one hazard (wind or surge).							

3.6 Clearance Time Findings

Tables 7, 8, and 9 provide agency-specific information on mobilization/decision times, clearance times, shutdown/closure time, respectively. The agencies are listed in the order in which they appear in the Master Facilities List. Timing requirements for facilities in each of four storm categories are provided. Some agencies have a significant range of decision times within each of the three tables. This variation represents the different times required to mobilize, clear or close different types of facilities. As an example, some facilities or a specific agency may have facilities such as a rail yard that will require more time to close than would a tunnel due to unique logistical considerations or the complexity of equipment associated with the facility. Likewise, within like facilities, such as roadways, there may also be ranges due to use, relative congestion levels, location, and elevation. The purpose of these summary tables is to present each agency with the range of time required to address all of their facilities in each operational phase (mobilization/decision, clearance, and shutdown/closure). It should be noted that all data included in these summary tables was vetted and approved by the listed agencies. Further detail on specific facilities is available on the Master Facilities List.

Table 7: Mobilization/Decision Time Requirements

Agency		Mobilization/Decision Time Requirements (hours)			
		Category 1	Category 2	Category 3	Category 4
AMTRAK		1	1	1	1
LI JURIS		1	1	1	1
LI FERRY		1	1	1	1
MTA BT		3	3	3	3
MTA LIRR	Tunnels	1	1	1	1
	Stations/Yards	8	8	8	8
MTA MNR		8	8	8	8
MTA NYCT	Depots	6	6	6	6
	Other	8	8	8	8
NACO		1	1	1	1
NACOBA		1	1	1	1
NJDOT		3	3	3	3
NJT		0.25	0.25	0.25	0.25
NYCDOT		3	3	3	3
NYSDOT8		3	3	3	3
NYSDOT10		0 to 3	0 to 3	0 to 3	3
NYSDOT11		3	3	3	3
NYSTA		1	1	1	1
PANYNJ		3 to 5	3 to 5	3 to 5	3 to 5
SUFFCO		3	3	3	3
WESTCO		3	3	3	3

Table 8 provides a representative account, by agency, of the clearance time requirements for each storm category in hours.

Table 8: Clearance Time Requirements

Agency		Clearance Time Requirements (hours)			
		Category 1	Category 2	Category 3	Category 4
AMTRAK		3	4	6	8
LI JURIS		5	9	15	16
LI FERRY		14	18	23	25
MTA BT	Tunnels	6	9	11	13
	Bridges/Approaches	7 to 9	9	11	13
MTA LIRR		3	4	6	8
MTA MNR		3	4	6	8
MTA NYCT		3	4	6	8
NACO		6	8	10	11
NACOBA		7	10	11	12
NJDOT		8.5	10.5	13.2	16.8
NJT		3	4	6	8
NYCDOT		5.4 to 9	5.7 to 16	6 to 22	6.1 to 25
NYSDOT8		7.5	9 to 11	11.9 to 21	12.9 to 23
NYSDOT10		12	15	19	24
NYSDOT11		5 to 10	5.2 to 18	5.8 to 31	6 to 33
NYSTA		7.5 to 10	9 to 14	12.5 to 22	13 to 25
PANYNJ		3 to 10	4 to 13.5	5 to 25	6 to 29
SUFFCO		12	15	19	24
WESTCO		7.5	9	11.9	12.9

Table 9 provides a listing of the shutdown/closure time ranges in hours for each agency.

Table 9: Shutdown/Closure Time Requirements

Agency	Shutdown / Closure Time Requirements (hours)			
	Category 1	Category 2	Category 3	Category 4
AMTRAK	1	1	1	1
LI JURIS	3	3	3	3
LI FERRY	8	8	8	8
MTA BT	1.25	1.25	1.25	1.25
MTA LIRR	1 to 4	1 to 4	1 to 4	1 to 4
MTA MNR	4	4	4	4
MTA NYCT	4	4	4	4
NACO	3	3	3	3
NACOBA	3	3	3	3
NJDOT	6	6	6	6
NJT	2	2	2	2
NYCDOT	1 to 6	1 to 6	1 to 6	1 to 6
NYSDOT8	6	6	6	6
NYSDOT10	0 to 6	0 to 6	0 to 6	6
NYSDOT11	6	6	6	6
NYSTA	2	2	2	2
PANYNJ	1 to 5	1 to 5	1 to 5	1 to 5
SUFFCO	6	6	6	6
WESTCO	6	6	6	6

Note: Where agencies were not able to provide an estimate of shutdown/closure time, an estimated time based on similar facility types owned by other agencies was used. These times were reviewed and approved by the project team and the stakeholder agencies before finalization.

3.7 Summary of Changes from 1995 to 2010

- Includes 327 transportation facilities in three states,
- Data collected in new datum, NAVD88,
- Integrates new SLOSH data from the 2010 model run,
- Updates and refines mobilization/decision, clearance, shutdown/closure, and pre-landfall hazard times for each facility.

4.0 Application of 2010 SLOSH Model

As part of this project, new surge vulnerability data was obtained from the 2010 SLOSH model. When compared to a facility's elevation, SLOSH provides an estimate of how significant surge-related flooding could be on a facility for different category storms. This section describes the SLOSH model and details its application to the Master Facilities List of critical transportation facilities described in Section 3.0.

4.1 Background and Previous SLOSH Models for Project Area

The SLOSH model was developed by the NOAA-NWS in the 1970s. The model computes the water height over a geographical area or basin resulting from storm surge. The expected surge values from several hundred hypothetical storm tracks are compiled into a composite map that represents potential areas of surge for the five modeled categories of hurricane. The primary use of the SLOSH model is to define flood-prone areas for evacuation planning. SLOSH output, including storm surge mapping, is used by the NHP when conducting HESs as a hazard analysis tool to help develop state and local evacuation plans and evacuation zones. It remains the only official surge model used by NHC.

The SLOSH model computes the maximum envelope of water (MEOW) or expected storm surge for multiple storm tracks. The maximum inundation for each MEOW, or the maximum of maximums (MOMs), compiles all the MEOWs to represent the worst elevation for each category of hurricane to form a line of demarcation that can be mapped. The *New York State Hurricane Evacuation Study TDR* (1993) relied on a SLOSH model run that was conducted in 1987. A subsequent SLOSH model run was conducted for the New York Basin in 2000 and was used as the basis for the Hazards Analysis in the *New York State Hurricane Evacuation Restudy TDR* (2009). This project takes advantage of a new analysis, conducted in 2010.

4.2 Methodology for Applying New SLOSH Model to Facilities

A major goal of the analysis was to compare the surge vulnerability of facilities included in the original 1995 work effort, based on the 1987 SLOSH run, with data from the 2010 Project, based on the 2010 SLOSH model. The "Worst Case 2010 SLOSH Surge Elevations at High Tide" section (Section *3.4.3 Discussion of Specific Data Fields*) explains the process for extracting this information from the SLOSH Display Program.

The intent was to determine, based on the new SLOSH data, if individual facilities' vulnerability to surge had changed. The new SLOSH runs provide the most up to date and accurate estimate of potential storm surge. Given the advances in technology, some facilities that were not previously susceptible to storm surge in 1987 may now be recognized as being vulnerable to storm surge flooding. Likewise, some facilities may no longer be deemed to be subject to storm surge in certain categories of storm.

4.3 Datum Conversion

One consideration that had to be addressed in comparing the 1987 data to the 2010 is that the benchmark for estimating the storm surge elevation, the vertical datum, changed from NGVD29 to NAVD88. If a flood depth is estimated to be ten feet, the datum answers the question, "Ten feet above what level?" The datum provides the base elevation in relation to which other elevations are measured. In most cases, this basis corresponds with MSL, so that measurements can be referred as "x" number of feet above MSL. NGVD29 was the system that had been used throughout most of the 20th Century. It was the basis for relating ground and flood elevations, but it has been replaced by the more accurate NAVD88. Because elevation has such an impact on floodplain management, it is important that the most accurate benchmark be used.

For each listed facility in this project that had elevation data included in the *Metro New York Hurricane Transportation Study TDR* (1995), the facility elevation was converted from NGVD29 to NAVD88. Those facilities that did not have elevation data included in the 1995 study, as well as all new facilities, were recorded in the NAVD88. This process allowed all facility elevations to be brought into a consistent measurement system, further allowing more accurate comparisons between facilities in relation to potential storm surge inundation.

4.4 Comparison of Previous SLOSH Surge Values to 2010 SLOSH

Due to improvements in modeling techniques and input data, the results of the SLOSH model runs conducted in 1987, 2000, and 2010 may vary slightly at any given location. The *New York State Hurricane Evacuation Study TDR* (1993) and the *Metro New York Hurricane Transportation Study TDR* (1995) both relied upon storm surge data results generated through a 1987 SLOSH model run. In those earlier studies, 100 geographically distributed locations throughout the Metro New York study area were selected as time history points to be used to help in determine pre-landfall hazard times. This project provides a comparison between the three SLOSH model year runs. For the 1987 SLOSH model run, single surge values are available for each category storm (Categories 1-4 on the Saffir-Simpson Hurricane Wind Scale (SS HW Scale)). For the 2000 and 2010 model runs, surge values are available for both the mean tide surge as well as the high tide surge. It should be noted that while the analysis compares depth of surge flooding, the data for 1987 and 2000 is in feet above NGVD29, while the 2010 results are in feet above NAVD88. The comparison of maximum surge heights at the 100 selected locations is presented in Appendix L.

4.5 Storm Surge Rate of Rise Issues

The SLOSH model provides a time-history tabulation of surge height, wind speed, and wind direction for critical locations within the project area. In the *Metro New York Hurricane Transportation Study TDR* (1995), approximately 100 pre-selected time history location throughout the project area provided a basis for calculating the location-specific rate of rise of storm surge, which in turn would impact pre-landfall hazard arrival. In general terms, the greater the potential maximum storm surge, the earlier a facility might be subject to surge effects before hurricane eye landfall. In this project effort, due to staffing and budgeting restrictions, the NHC did not provide updated time history data for specific locations. As a result, a scale based on data from the 1995 work effort was developed to account for rate of rise issues and to adjust the pre-landfall surge hazard time.

In the *Metro New York Hurricane Transportation Study TDR* (1995), the time-history values for Battery Park at the Battery on the southern tip of Manhattan Island were analyzed for hypothetical storm surge rate of rise. For other locations, comparisons of similar computed data to actual tide gage records have shown a correlation well within 20 percent. The SLOSH time-history analysis shows that the maximum hourly rise could vary from 6 feet for a Category 1 hurricane to 17 feet for a Category 4 storm. Due to the lack of new time study and hydrographic information for each facility, data from the previous study efforts was relied upon in addressing rate of rise issues in this analysis.

4.6 Rainfall Flooding

Potential freshwater flooding from rainfall accompanying hurricanes is usually addressed in general terms in HESs due to the wide variation in amounts and times of occurrence from one storm event to another. For most hurricanes, the heaviest rainfall begins near the arrival time of sustained tropical storm winds, however heavy rains exceeding 20 inches can precede an approaching hurricane by as much as 24 hours. Unrelated weather systems can also contribute significant rainfall amounts within a basin in advance of a hurricane. If a severe coastal storm causes riverine and storm surge flooding in a major river basin, the surge flooding usually occurs first, near the height of the storm, while the riverine flooding typically develops later as rainfall runoff accumulates and flows seaward. This sequence can vary, however, depending on storm track and forward speed as well as the pattern of rainfall preceding its arrival. For this project, locations and facilities that have historically flooded during periods of heavy rainfall are assumed to be vulnerable to freshwater flooding from hurricane conditions.

While a time history analysis was not conducted as part of this project, data introduced in the *Metro New York Hurricane Transportation Study TDR* (1995) has been included herein to provide an example of probable rates of rise of storm surge prior to hurricane landfall. The

1995 work effort included an example of hypothetical hurricane surge rate-of-rise at Battery Park, Manhattan in a 40 mph forward approach speed.

Figures 5 through 8 provide graphical and Tables 10 through 13 provide tabular data showing the rate of rise by storm category. The graphs show possible storm surge in feet at hourly intervals before the arrival of tropical storm force winds. The data table shows the actual time before peak surge at which specific surge levels may be expected. The basis for this analysis was the first iteration of the SLOSH model run, NY1, which supported the *Metro New York Hurricane Transportation Study TDR* (1995). The purpose of this analysis is to show the range of pre-landfall surge impacts that may be expected at Battery Park and to help substitute the estimated pre-landfall hazard time estimates from flooding employed in this project.

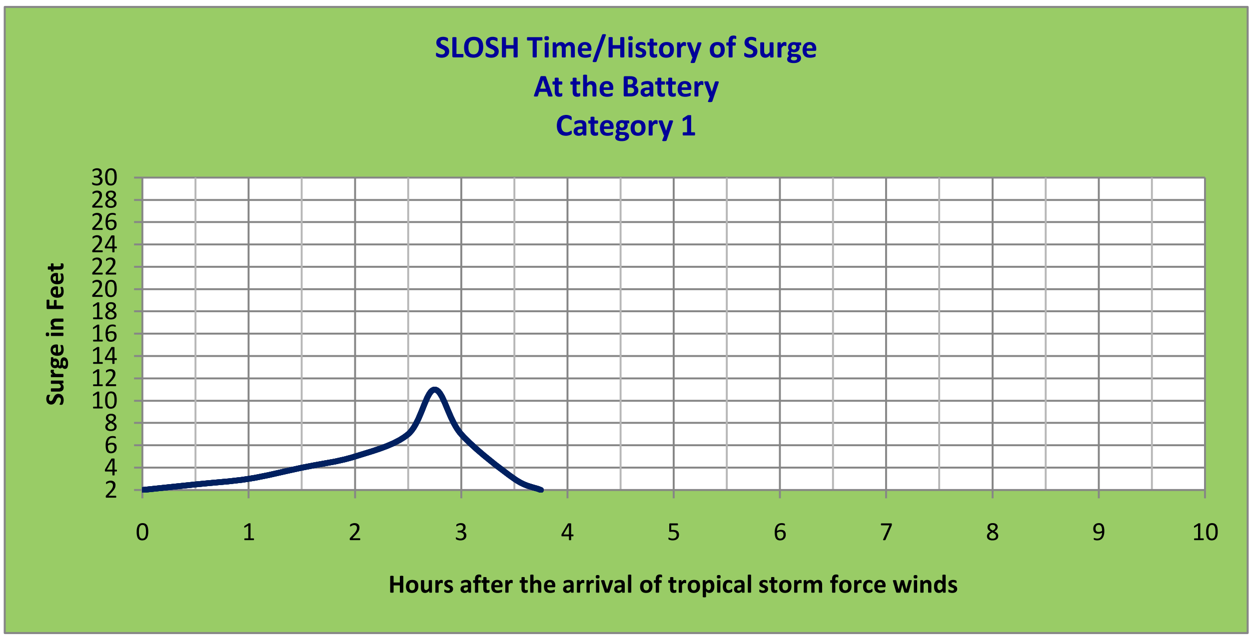

Figure 5: SLOSH Time/History of Surge at the Battery – Category 1

Table 10: Hypothetical (SLOSH) Hurricane Surge Rate of Rise at Battery Park, Manhattan for 40 mph Approach Speed – Category 1

Surge Elevation (feet)	Category 1 Before Peak Surge (hrs:min)	Maximum Hourly Rise
8	:10	**No estimate available.**
11	at peak	

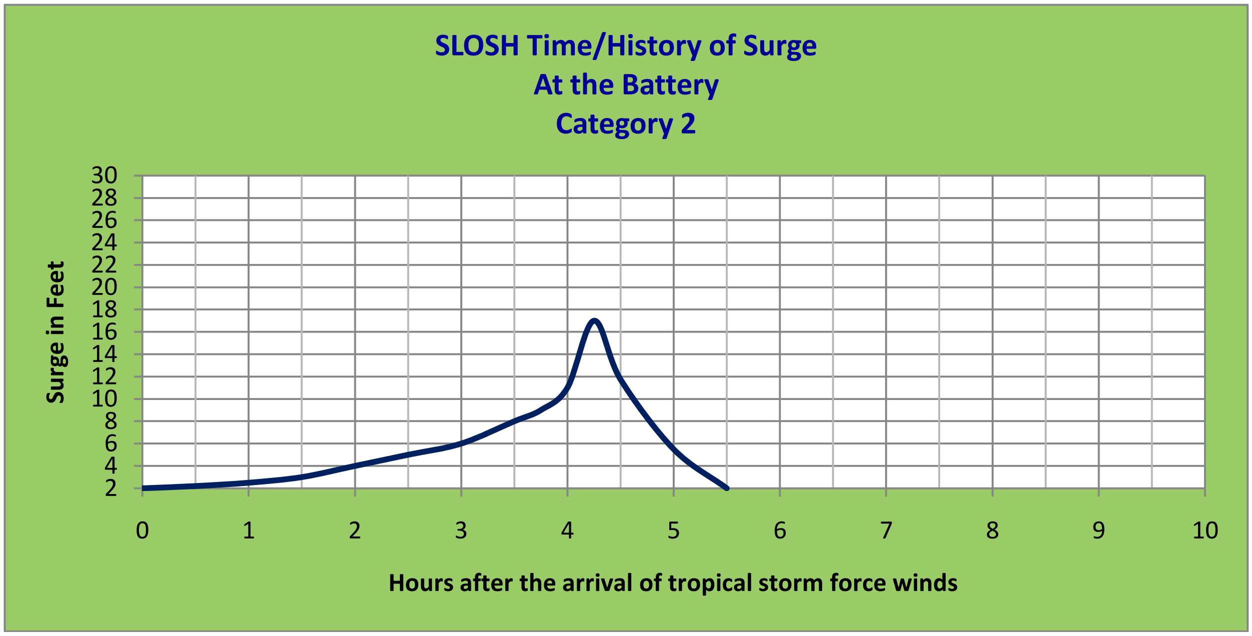

Figure 6: SLOSH Time/History of Surge at the Battery – Category 2

Table 11: Hypothetical (SLOSH) Hurricane Surge Rate of Rise at Battery Park, Manhattan for 40 mph Approach Speed – Category 2

Surge Elevation (feet)	Category 2 Before Peak Surge (hrs:min)	Maximum Hourly Rise
10	:30	**10 feet**
11	:25	
12	:15	
13	:12	
14	:07	
15	:05	
16	at peak	

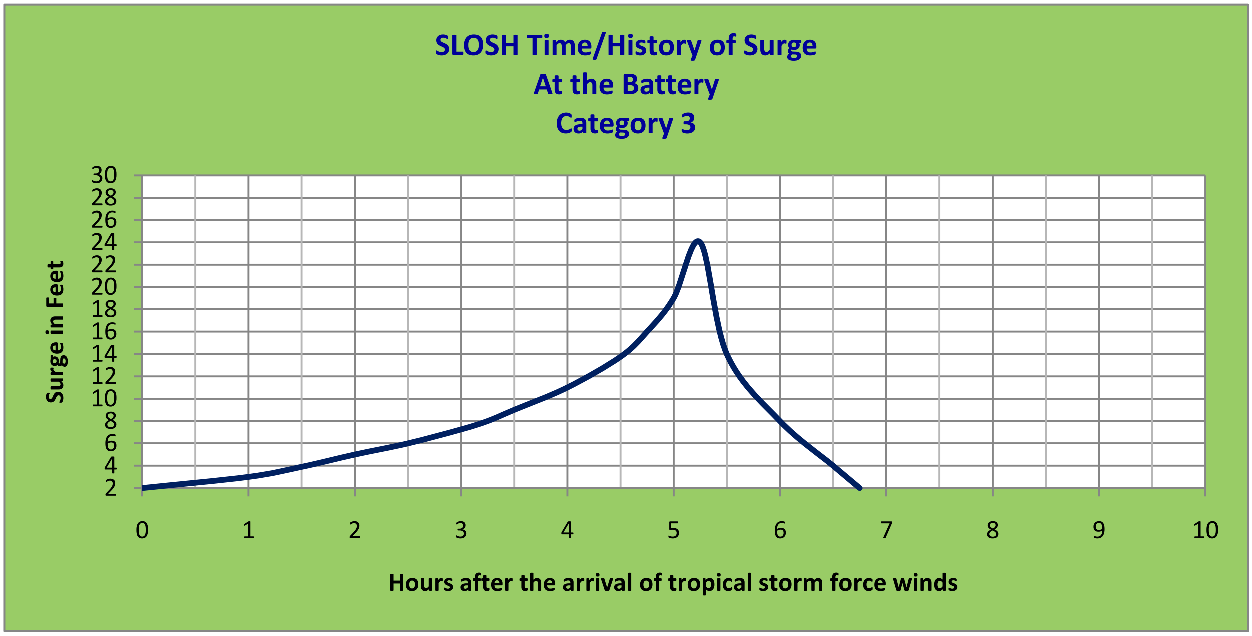

Figure 7: SLOSH Time/History of Surge at the Battery – Category 3

Table 12: Hypothetical (SLOSH) Hurricane Surge Rate of Rise at Battery Park, Manhattan for 40 mph Approach Speed – Category 3

Surge Elevation (feet)	Category 3 Before Peak Surge (hrs:min)	Maximum Hourly Rise
10	1:05	**13 feet**
11	:55	
12	:50	
13	:40	
14	:35	
15	:30	
16	:25	
17	:22	
18	:18	
19	:15	
20	:12	
21	:10	
22	:07	
23	:05	
24	at peak	

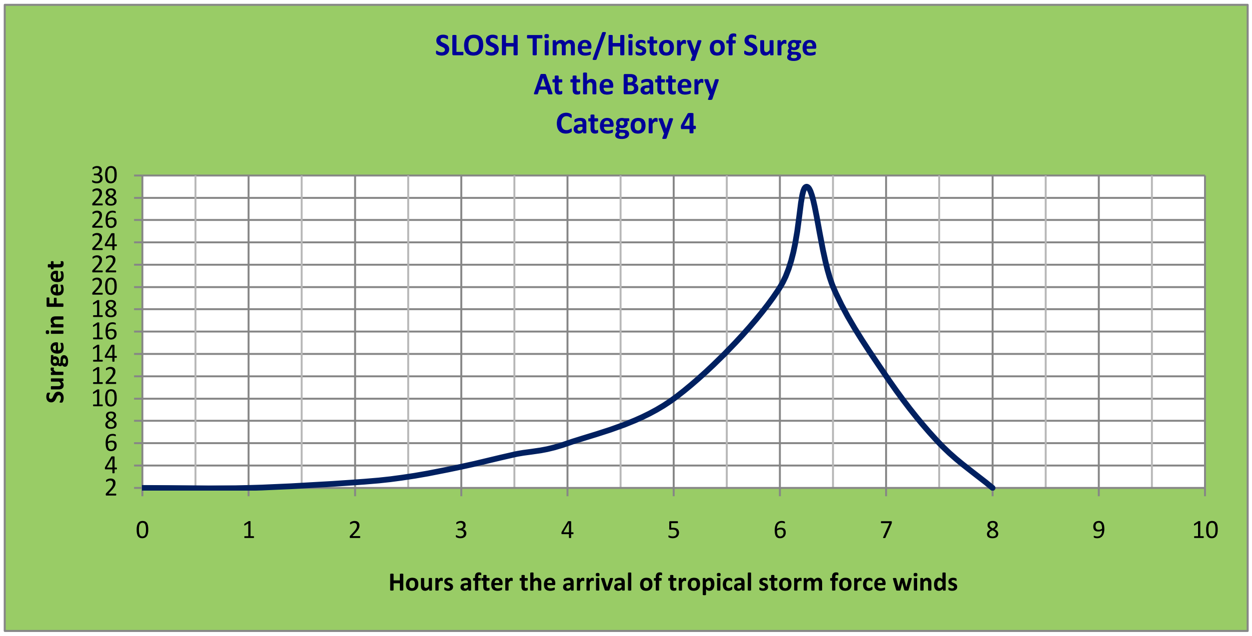

Figure 8: SLOSH Time/History of Surge at the Battery – Category 4

Table 13: Hypothetical (SLOSH) Hurricane Surge Rate of Rise at Battery Park, Manhattan for 40 mph Approach Speed – Category 4

Surge Elevation (feet)	Category 4 Before Peak Surge (hrs:min)	Maximum Hourly Rise
10	1:20	**17 feet**
11	1:10	
12	1:05	
13	1:00	
14	:55	
15	:45	
16	:40	
17	:35	
18	:30	
19	:25	
20	:20	
21	:17	
22	:12	
23	:10	
24	:08	
25	:07	
26	:06	
27	:05	
28	:04	
29	at peak	

4.7 Sample Facility Locations with Superimposed Surge Levels

In order to provide a visual representation of the potential impacts of surge, a series of well known facility locations throughout the region were selected. Similar processes for showing potential flooding had been employed in the *Metro New York Hurricane Transportation Study TDR* (1995).

Figures 9, 10, and 11 provide examples of estimated storm surge inundation for the Queens Midtown Tunnel (Queens Entrance), John F. Kennedy (JFK) Airport, and Exchange Place PATH Station. These images as well as fifteen additional locations can be found in Appendix M.

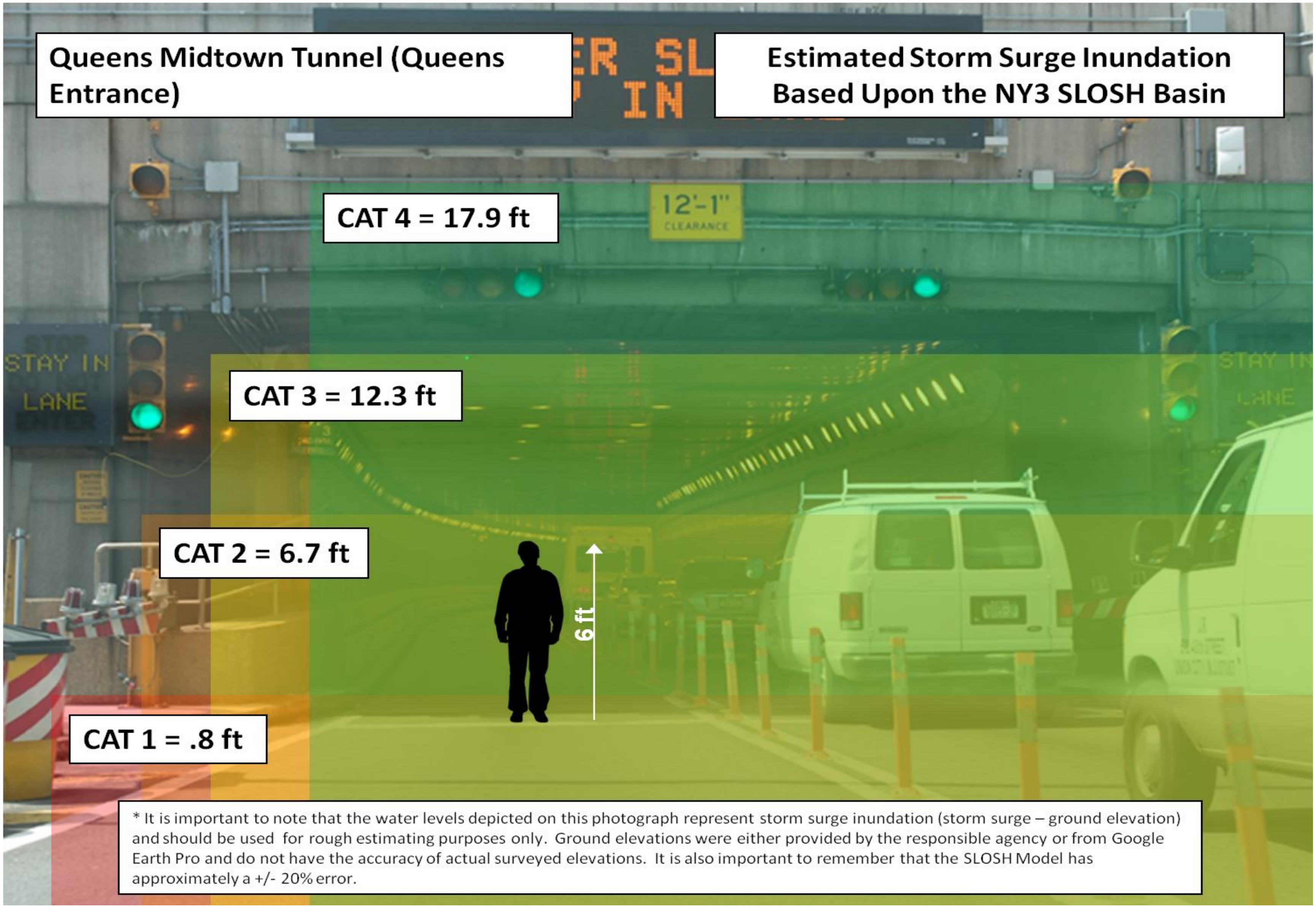

Figure 9: Queens Midtown Tunnel (Queens Entrance) Surge Levels

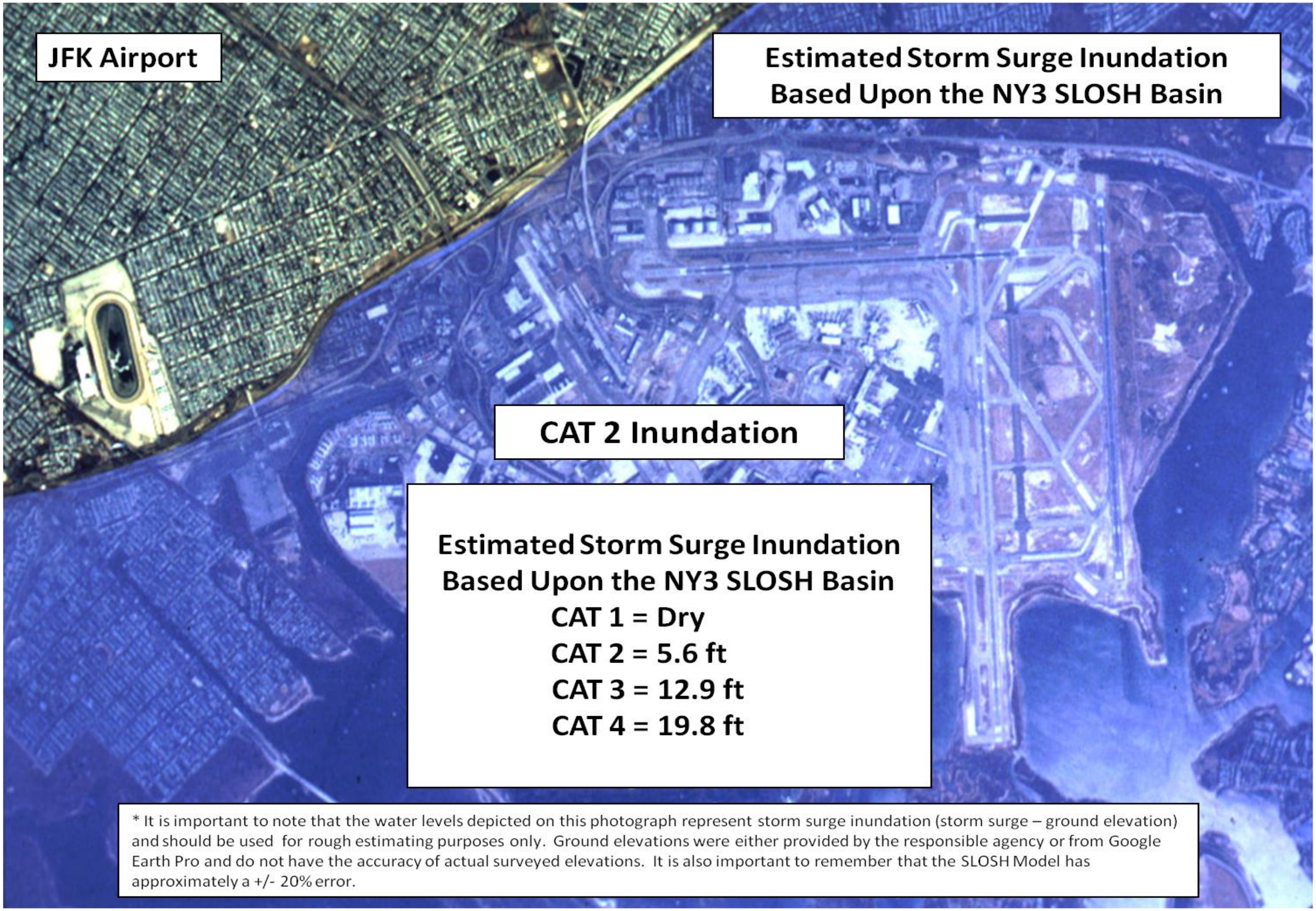

Figure 10: John F. Kennedy (JFK) Airport Surge Levels

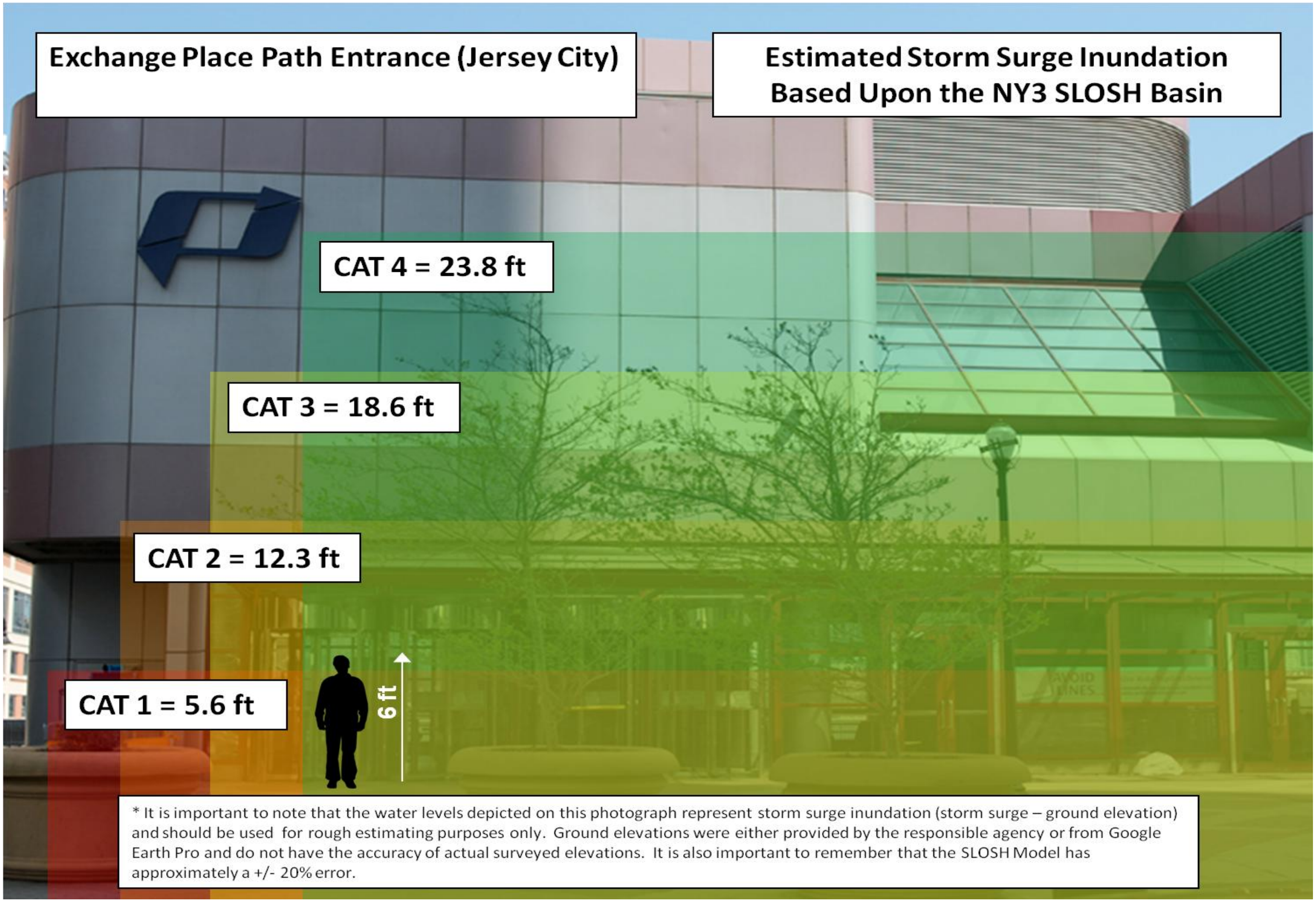

Figure 11: Exchange Place PATH Station Surge Levels

5.0 HURREVAC Critical Facilities Decision Making Tool

As part of this project, a number of operational tools were developed based on the agencies facilities update, including a facilities module incorporated into HURREVAC. This section describes the general functionality of the tool and the process for selecting representative facilities from the Master Facilities List. In addition, training on the Hurrevac2010 operational tools was conducted by SIS April 13 and 14, 2011 at NYCOEM. The training materials and documentation are included in Appendices N through U.

5.1 HURREVAC

HURREVAC, developed by SIS, is a storm tracking and decision assistance computer software program that tracks hurricanes using NHC's Forecast Advisories. The software accesses forecast track and wind extent information to develop interactive maps and reports that may be used to monitor the progress of a hurricane. The program also integrates rainfall, flood, tide, and river forecast information from other NOAA offices to assist users in evaluating inland flooding threats.

HURREVAC incorporates clearance times; which is the total time it takes to evacuate a jurisdiction. Jurisdictional clearance times in HURREVAC are based on worst case conditions, factoring in heavy background traffic, for New York, New Jersey, and Connecticut counties. It should be noted that facility-specific clearance times derived from the HES modeling process are used in the critical facilities tool and that these times may vary from the overall county clearance times included in HURREVAC.

The SIS Special Tools Section of the Hurrevac2010 User's Manual is included in Appendix V of this report.

5.2 Original HURREVAC Tool from Metro New York Hurricane Transportation Study TDR (1995)

HURREVAC provides emergency managers with a real time estimate of how many hours a jurisdiction has for preparation and planning in advance of a threatening storm. In the case of New York, estimated times related to mobilization/decision, clearance, shutdown/closure, and pre-landfall hazard times are also available. After initial collection of these timing parameters from the 1995 work effort, SIS designed the Critical Facilities Decision Making Tool in HURREVAC.

This special tool allowed transportation providers to view facility time components related to mobilizing decision making, serving evacuee travel movements, closing and securing facilities, and anticipating surge and wind hazards based on an approaching storm.

The development and inclusion of a HURREVAC tool in 1995 was a major step forward for the region's storm preparedness and was the first of its kind to be geared toward transportation agencies and their facilities. Individual facility timing was able to be viewed concurrent with general borough and county general evacuation time requirements in New York and northern New Jersey in the standard HURREVAC timing tables.

Training was held during the *Metro New York Hurricane Transportation Study TDR* (1995) to ensure agency representatives could effectively use the HURREVAC program as well as the original facilities plug-in.

5.3 Updated Critical Facilities Plug-In Tool for Hurrevac2010

The 2010 Metro NY Project reduced the total number of 327 tracked facilities from the Master Facilities List to 132 locations. In some instances one facility was selected to represent multiple facilities. In addition to nearly doubling the number of facilities that users can monitor in HURREVAC, the tool developed in this effort benefits from the increased functionality built into Hurrevac2010.

Features included in the updated tool set include:

- An updated presentation of facilities data incorporating discrete action periods for mobilization/decision, clearance, shutdown/closure, and pre-landfall hazard times.
- The ability to marry the discrete action periods with real-time estimated storm hazard arrival data related to both the eye and leading edge of sustained tropical storm winds, both of which can be quite different for different size storms and forward speed/direction of movement.
- Traditional HURREVAC timing detail tables with the ability to select the newest analysis and vulnerability reports contained in Hurrevac2010.
- A comprehensive filtering/sorting feature allowing the user to sort facilities by hazard type (wind or surge), geographic jurisdiction (17 individual jurisdictions in New York, New Jersey, and Connecticut), facility owners (19 transportation provider agencies), and facility type (11 types of highway, transit, air, marine choices).
- Specialized individual facility features including options to allow the addition of time for unusual situations and tables for evacuation timing for a single facility.

A user guide and help document is incorporated into the Hurrevac2010 program to provide the necessary detail on the features listed above.

5.4 Facility Selection for HURREVAC Rationale

The project team, with input from agency stakeholders, selected 132 representative locations from the Master Facilities List to be included in HURREVAC. The selected locations were based on critical elevations, geographic dispersion, and coverage of all facility and hazard types. The *Metro New York Hurricane Transportation Study TDR* (1995) was consulted to assist in identifying critical roadway segments. Table 14 provides a listing for each agency, and the number of facility locations included in Hurrevac2010. A complete listing of the facility locations included in HURREVAC is included in Appendix J.

Table 14: Facility Locations in Hurrevac2010 – By Agency

Agency	Number of Facilities in Hurrevac2010
AMTRAK	2
LI JURIS	2
LI FERRY	3
MTA BT	14
MTA LIRR	10
MTA MNR	10
MTA NYCT	22
NACO	2
NACOBA	1
NJDOT	7
NJT	6
NYCDOT	10
NYSDOT8	1
NYSDOT10	9
NYSDOT11	15
NYSTA	2
PANYNJ	14
SUFFCO	1
WESTCO	1

As a storm approaches, the rise of coastal water will be quite rapid – for a Category 3 hurricane, flood depths in the region could rise as much as 12 feet per hour. This fact argued for including only the most vulnerable locations in HURREVAC and only those which might determine controlling system-wide shutdown/closure decisions. However, agencies must be cautioned – if they implement physical flood protection and mitigation measures for a specific low spot, they cannot assume that the measure solves system wide vulnerabilities without looking at the next most vulnerable location on the Master Facilities List. Consultant recommends that every two to three years agencies should revisit their Master Facilities List and HURREVAC selected locations to see if any capital improvements or information has changed that affects these facilities.

Some general notes regarding facility selection for HURREVAC include:

- AMTRAK — The two lowest system entry points for surge were selected. These determine system integrity and continuance.
- LI FERRY – Has three locations represented in HURREVAC. The Fire Island Ferries entry represents three dock locations.
- MTA BT — The Brooklyn Battery Tunnel locations from the previous *Metro New York Hurricane Transportation Study TDR* (1995) were replaced with a newly identified lowest entry point for surge. The lowest entry point for Queens Midtown Tunnel was selected. Selected the center span and lowest bridge approach for high-level bridges with the exception of RFK and Henry Hudson Bridge approaches which are higher than other bridge approaches.
- MTA LIRR — Two tunnel locations were selected which are the lowest entry points for surge. Several of the lowest station/yards were included, representing a wide geographic area, including facilities which could trigger the relocation of equipment system-wide.
- MTA MNR — Several of the lowest points on the Hudson Line which are geographically dispersed and could trigger system closure were selected. A flood vulnerable New Haven line location could control the ability of that line to operate or close was also selected. The Grand Central Station serves as the terminal for rail and subway lines and was selected as a single entry due to its high vulnerability.
- MTA NYCT — Eight locations were selected representing key tunnels that have elevations below 10 feet and which represent underground operating corridors with surge vulnerability. In addition, several geographically dispersed depot locations below 10 feet were selected.
- NACO — Both bridge approach entries were selected due to extremely low lying, surge vulnerable elevations.
- NACOBA — Atlantic Beach Bridge, one entry, a low bridge approach, was selected.
- NJDOT — Geographically dispersed locations below 8 feet (approximately) were selected. Once these locations compromised, all of the other like locations will be closed as well.
- NJT — No new elevation data was provided to NYCOEM or USACE as part of this project. However, two vulnerable locations share PATH track and equipment and have been included based on information available from PANYNJ.
- NYCDOT — All the locations selected have critical vulnerability to wind or flood.
- NYSDOT10 — The locations that were selected are generally the lowest for any one roadway facility.
- NYSDOT11 — Geographically dispersed locations that serve evacuation movements and which are generally below 10 feet were selected. The critical locations include FDR

Drive, the BQE, and Belt Parkway. Arguably more locations could be selected but these ten provide a representative sample and can serve as triggers for decision making.

- NYSTA — The lowest point on I-95 was selected. The center span for the Tappan Zee Bridge was also selected as winds will cut off the bridge facility before highway approach flooding (if any) occurs.
- PANYNJ — For PATH system, the lowest entry points for surge and power substation locations extremely vulnerable to surge were selected. For the Lincoln and Holland Tunnels, five of the lowest points were selected. They include points below eight feet for the Holland Tunnel and below ten feet for the Lincoln Tunnel. All listed PANYNJ bridges were selected. Locations include all center spans and only those approaches with flood issues. All airports were also selected prior to eye landfall, and that are also subject to rising water, have a pre-landfall wind hazard time added to the mobilization/decision time.

5.5 Facility Timing for Wind and Surge

In calculating the hazard arrival time for facilities, HURREVAC must differentiate between facilities which will be cut off by early arrival of winds and those cut off by early surge flooding. Unlike the 1995 Metro New York HURREVAC tool, this new tool in Hurrevac2010 determines and reports the expected real-time arrival of both the eye and the leading edge of sustained tropical storm winds based on the strength, size, and forward speed of the storm.

For high-rise facilities such as bridges, an offset of approximately one, two, or three hours is added to the forecasted 39 mph ground-level wind arrival time to account for the fact that winds are routinely stronger at these high altitudes and the storm effects will be felt earlier. The facilities section (*3.0 Agency Facility Updates*) of this report discusses in more detail the specific values used for facilities at various heights.

With wind-affected facilities, HURREVAC computes the direct hit arrival time of 39 mph winds to the facility, and subtracts the combined times for mobilization/decision, clearance, shutdown/closure, and pre-landfall hazard times to arrive at a proper decision time.

Those facilities which are affected first by flooding (specifically flooding from storm surge as determined by the SLOSH model) were identified in Section *3.0 Agency Facility Updates*. HURREVAC reports surge flooding that would occur assuming a direct hit or worst case assumption.

The SLOSH model data results in a time, in hours, before the arrival of the eye, when surge flooding would commence at the facility. This may range from zero hours (surge flooding arrives only when eye arrives) or as much as seven hours before the eye for a severe storm approaching from a critical direction. In most cases, the surge flood-affected facilities will have much later decision times than the wind-affected ones.

With surge flood-affected facilities, HURREVAC first computes the direct hit arrival time of the storm's eye or center in the area, and subtracts the pre-landfall flooding time in hours as determined by SLOSH for the worst case. After the flood arrival time is determined from the SLOSH model offset, the program then subtracts the combined times for mobilization/decision, clearance, and shutdown/closure, and pre-landfall hazard times to arrive at a proper decision time.

5.6 Sea Island Software Support and User Help

SIS and the contractor provided guidance and support to the project team in the development of the facilities timing tool based on past project experience and familiarity with HURREVAC. While some of the functionality of the facilities tool was based on the version developed along with the *Metro New York Hurricane Transportation Study TDR* (1995) effort, this version takes advantage of the user interface improvements integrated into the newest platform of HURREVAC, updated in 2010 (often referred to as Hurrevac2010). SIS has published a *Hurrevac2010 User's Manual* (updated 2011), which was revised and updated as part of this project effort. The manual provides a complete overview on the use of HURREVAC, with sections related to storm features, annotation, reports, browser information, basic model utilities, other forms and special tools. The special tools section, which was significantly revised as part of this effort, provides guidance on the use of the facilities timing tool (as well as the risk profile which is described in more detail in Section 6.0 of this report). The *Hurrevac2010 User's Manual* in its entirety is accessible via www.hurrevac.com.

6.0 HURREVAC Risk Profile Module

A risk profile is a state specific tool that compiles both objective data and subjective threat assessment information, allowing decision makers the opportunity to assess a range of information at each hurricane advisory. This enables them to be better informed of relative risks and track trends from advisory to advisory. In order to provide regional HURREVAC users with a tool to better assess regional risks and to support more informed evacuation decision making, a hurricane risk profile was developed for the New York metropolitan area as part of this project. A digital version of the risk profile was developed as an integrated stand alone module within HURREVAC. The risk profile includes evaluation scopes pertinent to both state (New York) and local (Metro New York) users.

6.1 Risk Profile Module Purpose and Background

Risk profiles have been developed within HURREVAC for Florida, Virginia (including northeastern North Carolina) and New York (including northeastern New Jersey). As with the other risk profiles upon which its structure is based, the 2010 Metro New York risk profile includes a series of threat assessment topics; Risk of Impact, Storm Intensity, Evacuation Considerations, as well as Storm Surge and Flooding. These threat assessment topics are consistent between both state and local risk profile scopes. In HURREVAC, the topics are assigned a letter code ranging from Topic A through Topic D. A brief description of the topics is included below:

- Risk of Impact (Topic A) – This topic defines the area at risk and quantifies the degree of risk to that area.
- Storm Intensity (Topic B) – This topic provides guidance on what intensity (storm category) the storm may have when it impacts the area.
- Evacuation Considerations (Topic C) – This topic addresses other storm characteristics and regional evacuation timing information that may affect evacuation decision making.
- Storm Surge and Flooding (Topic D) – This topic considers threats posed by heavy rainfall and storm surge brought about by an approaching storm.

6.2 Metro New York Risk Profile Questions / Scoring Criteria

Within each topic area there are a series of numbered questions, or criteria. In the Metro New York risk profile application, individual criteria may differ between the state and county risk profiles, as different risk factors are applicable to the state and county levels. For each criteria question, a series of three answers, or conditions, can apply. The answers track the relative risk posed by each criteria and are color coded in HURREVAC by green, yellow and red shaded squares, with green corresponding to the lowest risk and red to the highest risk.

The criteria employed in the Virginia risk profile provided the project team with a study point for discussions. Through collaborative discussions involving a range of subject matter experts from NYCOEM, USACE, NWS, SIS, and the contractor, the criteria were elaborated, customized for the region, and finalized. As a statewide tool, profile criteria were developed for the State of New York and the Metro New York region. As noted, the risk profile includes screens for both the Metro New York region (which includes jurisdictions in New York City, Long Island, Northeast New Jersey, and Southern Connecticut), as well as New York State. The State screen is helpful in tracking storm progress and inland wind threats outside of the Metro New York region.

Two additional indicators have been applied to key questions, which NYCOEM has designated; "of concern" and "critical". These indicators are present in both the State and the Local (Metro) screens for each of the four themes. When these questions reach the specific risk level of yellow or red, they are annotated by either an exclamation point within a yellow triangle ( ) denoting "critical", or an exclamation point within a white circle ( ) denoting "of concern". This provides an additional level of prompting to decision makers when key criteria are met, even though the overall aggregated risk may appear low. The State profile has six key questions that may generate an "of concern" indicator ( ) and four key questions that may generate a "critical" indicator ( ). The Local profile has six key questions that may generate an "of concern" indicator ( ) and six key questions that may generate a "critical" indicator ( ). A listing of all key questions showing which may generate an "of concern" indicator ( ) and/or a "critical" indicator ( ) is included in the Hurrevac2010 Special Tools Section in Appendix V.

In order to better demonstrate how the risk profile display appears, Hurricane Earl (formed August 25, 2010 and dissipated on September 4, 2010) was run in HURREVAC. Tables 15 through 18 display the State and Local criteria data resulting from this historical storm using Advisory 30 dated September 1, 2010.

Users can complete the risk profile data entry for each topic area after each hurricane advisory. The profile forms are then aggregated into State and Local Summaries. The summaries provide a quick snapshot of the risk level assigned to each criterion (noted by the color code and any special indicators) by advisory. A screen shot of a local risk profile summary populated with historical storm Earl, as described above, is provided in Figure 12.

Table 15: State and Local Criteria and Conditions – Risk of Impact (Topic A)

Criteria	Conditions
Hurricane Risk Profile (State) for New York	
1. Is a NY/Northern NJ county within the NHC 120-hour average forecast error cone? Ex.: In 46 hr error ellipse = ⚠ Critical	Red = Within 48 hours Yellow = Within 72 hours Green = > 72 hours or not in error cone
2. Are NHC Watches or Warnings in effect anywhere from Manasquan, NJ to Port Jefferson Harbor, NY? Ex: Tropical Storm Warning = ⚠ Critical	Red = Hurricane Warning Yellow = TS Warning or Hurricane Watch Green = TS Watch or none
3. Highest coastline NHC 64kt wind probability from Atlantic City, NJ to Montauk Point, NY? Ex.: 7% for 64kt (22% for 50kt, 53% for 34kt)	Red = Greater than 18% Yellow = 11% to 18% Green = Less than 11%
4. Increase or decrease of maximum probability since last advisory? Ex.: Decreased 9% to 7%	Red = Increased in percent Yellow = Remained same percent Green = Decreased in percent
5. Storm's steepest forecast angle of approach to NY/Northern NJ? Ex.: Does not cross NY/Northern NJ coastline	Red = 120-160 degs (4 to 5 o'clock) Yellow = 161-199 degs (5 to 7 o'clock) Green = All other approaches (or N/A)
6. Forecast peak wind in NY/Northern NJ based on the 72-hour forecast track? Ex.: 49 mph in Suffolk	Red = Hurricane force (> 73 mph) Yellow = Between 58 and 73 mph Green = Less than 58 mph
Hurricane Risk Profile (Local) for NYC Metro County NY	
1. Is this county within NHC 120-hour average forecast error cone? Ex.: Outside Error Cone	Red = Within 48 hours Yellow = Within 72 hours Green = > 72 hours or not in error cone
2. Are NHC Watches or Warnings in effect for your county OR if inland county…nearby coast? Ex.: Tropical Storm Watch	Red = Hurricane Warning Yellow = TS Warning or Hurricane Watch Green = TS Watch or none
3. What is the NHC 64kt wind probability nearest your county? Ex.: 0% for 64kt (6% for 50kt, 32% for 34kt)	Red = Greater than 18% Yellow = 11% to 18% Green = Less than 11%
4. Have the wind probabilities nearest your county increased or decreased since the last advisory? Ex.: Decreased 1% to 0%	Red = Increased in percent Yellow = Remained same percent Green = Decreased in percent
5. Storm's steepest forecast angle of approach to NY/Northern NJ coastline? Ex.: Does not cross NY/Northern NJ coastline	Red = 120-160 degs (4 to 5 o'clock) Yellow = 161-199 degs (5 to 7 o'clock) Green = All other approaches (or N/A)
6. Forecast peak wind in your county based on the 72-hour forecast track Ex.: < 39 mph (34kt)	Red = Hurricane force (> 73 mph) Yellow = Between 58 and 73 mph Green = Less than 58 mph

Table 16: State and Local Criteria and Conditions – Storm Intensity (Topic B)

Criteria	Conditions
Hurricane Risk Profile (State) for New York	
1. What is the current intensity of the storm? Ex.: Cat 4 major hurricane = ⚠ Critical	Red = Major hurricane (Cat 3/4/5) Yellow = Hurricane (Cat 1 or 2) Green = Tropical storm or lower
2. What is the forecast storm intensity at closest approach? Ex.: Cat 2 Hurricane = ⓘ Of Concern	Red = Major hurricane (Cat 3/4/5) Yellow = Hurricane (Cat 1 or 2) Green = Tropical storm or lower
3. Difference in central pressure from last advisory? Ex.: No change 0 millibars (mb) (941 to 941mb)	Red = Decrease by more than 5 mb Yellow = Decrease by less than 5 mb or Same Green = Increase
4. Do hurricane force winds normally penetrate inland in a storm with this strength and forward speed? Ex.: Greater than 5 inland counties = ⓘ Of Concern	Red = Greater than 5 inland counties Yellow = 1 to 5 inland counties affected Green = Coastal counties only (or not in error cone)
Hurricane Risk Profile (Local) for NYC Metro County NY	
1. What is the current intensity of the storm? Ex.: Cat 4 major hurricane = ⚠ Critical	Red = Major hurricane (Cat 3/4/5) Yellow = Hurricane (Cat 1 or 2) Green = Tropical storm or lower
2. What is the forecast storm intensity at closest approach? Ex.: Cat 2 Hurricane = ⓘ Of Concern	Red = Major hurricane (Cat 3/4/5) Yellow = Hurricane (Cat 1 or 2) Green = Tropical storm or lower
3. Difference in central pressure from last advisory? Ex.: No change 0 millibars (mb) (941 to 941 mb)	Red = Decrease by more than 5 mb Yellow = Decrease by less than 5 mb or Same Green = Increase
4. Do hurricane force winds normally reach this county in a storm with this strength and forward speed? Ex.: Not in error cone	Red = Hurricane force…73 mph or greater Yellow = 58 to 73 mph Green = Less than 58 mph or not in error cone

Table 17: State and Local Criteria and Conditions – Evacuation Considerations (Topic C)

Criteria	Conditions
Hurricane Risk Profile (State) for New York	
1. Average forward speed over 72-hour forecast period or until landfall? Ex.: Average forward speed 24 mph	Red = 30 mph or greater Yellow = 20 to 29 mph Green = Less than 20 mph
2. Has the radius of maximum tropical storm force winds expanded from previous advisories? Ex.: No expansion or decrease	Red = Expanding over previous two advisories Yellow = Expanding since the last advisory Green = No expansion or decrease
3. Number of hours until onset of tropical storm force winds (39 mph) in NY/Northern NJ based on the forecast track? Ex.: 44 hrs in Suffolk	Red = Within 24 hours Yellow = Between 24 and 36 hours Green = Greater than 36 hours or none
4. Earliest NHC Forecast Track (CPA) Decision Time for counties within the 72-hour average forecast error cone? Ex.: 44 hrs Suffolk 09/03/10 1 PM	Red = Decision time has passed Yellow = 12 hours or less to decision time Green = Greater than 12 hours from decision time
5. Earliest Direct Hit Decision Time for counties within the 72-hour average forecast error cone? Ex.: 41 hrs NYC Metro 09/03/10 10 AM	Red = Decision time has passed Yellow = 12 hours or less to decision time Green = Greater than 12 hours from decision time
6. Does the storm event coincide with a holiday period? Ex.: +/- 1 week of Labor Day	Red = Within 1 week of July 4 or Labor Day weekend Yellow = After July 4 week and before Labor Day weekend Green = Outside of holiday period
Hurricane Risk Profile (Local) for NYC Metro County NY	
1. Average forward speed over 72-hour forecast period or until landfall? Ex.: Average forward speed 24 mph	Red = 30 mph or greater Yellow = 20 to 29 mph Green = Less than 20 mph
2. Has the radius of maximum tropical storm force winds expanded from previous advisories? Ex.: No expansion or decrease	Red = Expanded over previous two advisories Yellow = Expanded since the last advisory Green = No expansion or decrease
3. Maximum clearance time for your county? (If non-HES risk county then standard 6 hrs used) Ex.: 35 hrs for Cat 4 Medium Occ./Medium Resp. = ⚠ Critical	Red = County with 24 hours or greater Yellow = County with 16 to 23 hours Green = Less than 16 hours
4. Number of hours until onset of tropical storm force winds (39 mph) on the forecast track? Ex. Not forecast within 72 hours	Red = Within 24 hours Yellow = Between 24 and 36 hours Green = Greater than 36 hours or none
5. Earliest NHC Forecast Track (CPA) Decision Time for this county if within the 72-hour wind swath? Ex.: No tropical storm winds forecast	Red = Decision time has passed Yellow = 12 hours or less to decision time Green = Greater than 12 hours from decision time
6. Assuming a Direct Hit track…what is the Decision Time for this county? Ex.: 6 hrs 09/01/10 11 PM	Red = Decision time has passed Yellow = 12 hours or less to decision time Green = Greater than 12 hours to decision time
7. Period of day when Decision Time for your county occurs? Ex.: 11 PM Wed	Red = 11PM-6AM or 9AM-4PM Mon-Fri Yellow = 4PM-11PM Green = 6AM-9AM or 9AM-4PM Sat-Sun

Table 18: State and Local Criteria and Conditions – Storm Surge and Flooding (Topic D)

Criteria	Conditions
Hurricane Risk Profile (State) for New York	
1. Greatest rainfall forecasted for NY/Northern NJ county in next 72 hours? Ex.: Data not available for advisory > 24 hours old	Red = Greater than 6 inches Yellow = 3 to 6 inches Green = Less than 3 inches (or NA)
2. What is the highest astronomical tide predicted within the 24-hour period prior to closest approach? Ex.: Lower than average	Red = Higher than average (spring tide) Yellow = Near average Green = Lower than average (neap tide)
3. Timing of storm's closest approach with diurnal tide cycle at gage closest to forecast track? Ex.: SANDY HOOK: 0 hrs to high tide of 4.17 ft, +6 hrs to low tide of .15 ft	Red = Near high tide Yellow = Near mid tide Green = Near low tide
4. Has the radius of maximum hurricane force winds expanded from previous advisories? Ex.: No expansion or decrease	Red = Expanding over previous two advisories Yellow = Expanding since the last advisory Green = No expansion or decrease
Hurricane Risk Profile (Local) for NYC Metro County NY	
1. Amount of rainfall forecasted for this county in the next 72 hours? Ex.: Data not available for advisory > 24 hours old	Red = Greater than 6 inches Yellow = 3 to 6 inches Green = Less than 3 inches (or NA)
2. Are tides higher than normal within the 24-hour period prior to closest approach? Ex.: Lower than average	Red = Higher than average (spring tide) Yellow = Near average Green = Lower than average (neap tide)
3. Timing of storm's closest approach with diurnal tide cycle at gage closest to county? Ex.: SANDY HOOK: 0 hrs to high tide of 4.17 ft, +6 hrs to low tide of .15 ft	Red = Near high tide Yellow = Near mid tide Green = Near low tide
4. Has the radius of maximum hurricane force winds expanded from previous advisories? Ex.: No expansion or decrease	Red = Expanding over previous two advisories Yellow = Expanding since the last advisory Green = No expansion or decrease

Figure 12 is a screen shot of the risk profile summary. The summary screen (available both for the New York State and New York Metro region analyses) catalogues the previous twelve NWS hurricane advisories and provides a graphical depiction of risk level changes within each criteria area. While there is no hard and fast rule associated with when an evacuation should be ordered, the tool allows decision makers to track trends in emerging risk as a storm approaches. Red increasing numbers of "critical" indicator notes, as they begin to appear over subsequent advisories, should suggest to decision makers that an evacuation may need to be ordered. Internal protocol may be developed to further support decision makers in interpreting and acting upon the data as presented.

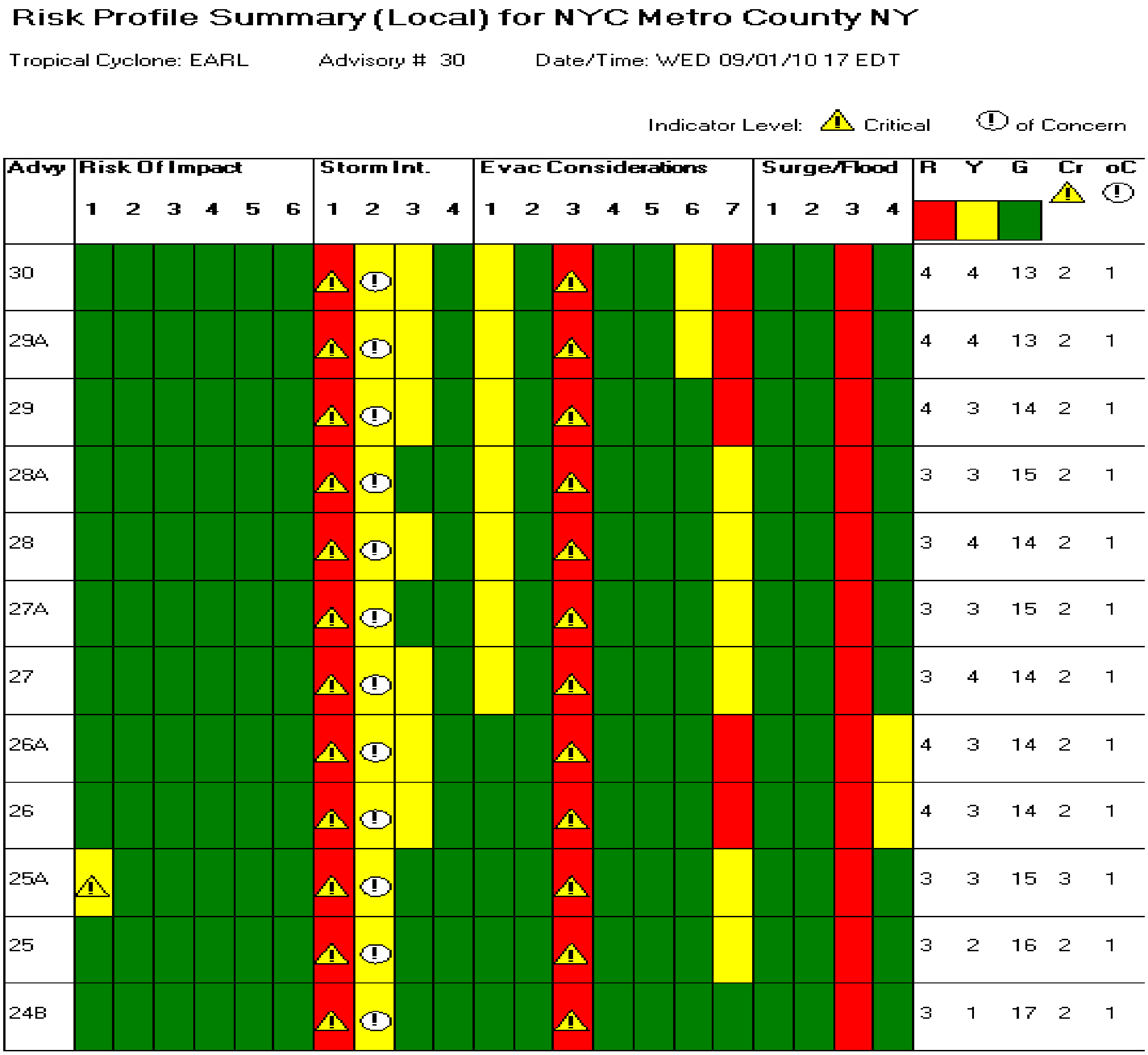

Figure 12: Risk Profile Summary (Local) for NYC

6.3 Sea Island Software Support and User Help

SIS has edited the Hurrevac2010 User's Manual to describe the special tools developed as part of this project, including the facilities timing reports as well as the risk profile. The Special Tools section of the revised manual is included in Appendix V.

7.0 Evacuation Dashboard Prototype

An electronic prototype of a common operating evacuation dashboard was developed as part of this project. The prototype provides a concept for how emergency managers and transportation agency executives monitor critical information regarding an approaching storm. This prototype is developed for use in the NYCOEM Emergency Operations Center (EOC), although the concept can be applied to any stakeholder or jurisdiction in the project area.

The product is designed to be manually populated by key agency emergency operations staff, with a goal of providing executive level decision makers with a common operating picture of the current situation in an attractive, user-friendly format. The interactive product allows decision makers to focus on key benchmarks regarding expected hazards, evacuee notification, real-time public response, and regional transportation facilities' impacts and status. The ultimate goal of the use of the dashboard is to facilitate consistent information and to prioritize coordination between decision makers.

7.1 Background

Initial dashboard concepts were vetted with NYCOEM and agency stakeholders to determine the key information stakeholders felt was necessary for inclusion. Since this is a new concept for evacuation operations, certain information is easier to obtain than others, but all information in the prototype was determined to be critical for decision makers during a potential evacuation. Through this process, NYCOEM leadership decided the prototype tool should be presented in an attractive, one-sheet "scorecard" format that could be used even if computer interfaces were non-functional as a storm approached. A hard copy of the dashboard was refined as some of the important input facility data was finalized. The final hard copy dashboard was converted into an electronic format to demonstrate to NYCOEM and other potential users how the product might function interactively through a computer-based interface in an EOC environment.

7.2 Dashboard Overview

The overall goal of the dashboard is to provide emergency management and transportation agency executives with an easy to use and interpret snapshot of critical situational information to support evacuation decision making. The prototype dashboard consists of four distinct hypothetical modules, which suggest key information that could be incorporated into a data-supported platform. Currently these modules are not linked to a live database.

- *Key Storm Information* – Displays a snapshot of the current position and strength of the storm as well as projected arrival characteristics. A summary of critical, moderate, and low risk profile factors from the Hurrevac2010 risk profile module is also included and summarized for the previous and current advisory.

- *Evacuation Notification and Shelter Status* – Would indicate which level of evacuation zone (if any) has been asked or ordered to leave for each borough of New York City, Nassau, Suffolk, and Westchester, and selected New Jersey counties. A shelter status feature is also included which allows the user to enter the number of shelters opened and occupancy information.
- *Real-Time Public Response Snapshot* – Provides a representative look at the evacuation compliance of specific areas. The areas selected in the mock-up are those at risk of significant storm surge inundation, and which have low automobile ownership and limited mass transit access, as determined by the *New York State Hurricane Evacuation Restudy TDR* (2009). This module is included only for discussion purposes since a functional data source has not yet been identified.
- *Critical Interregional Transportation Facilities Status* – The final module shows a very small, but targeted sample of the hundreds of regional transportation facilities included in the Metro NY Evacuation Project. Facilities are grouped by general function/direction of travel and key attributes such as facility owner and mode are indicated. Current evacuation congestion, closure condition, and time until closure would be provided for agency executives and other dashboard users.

Figure 13 shows the prototype dashboard. Each module is described in further detail in this section.

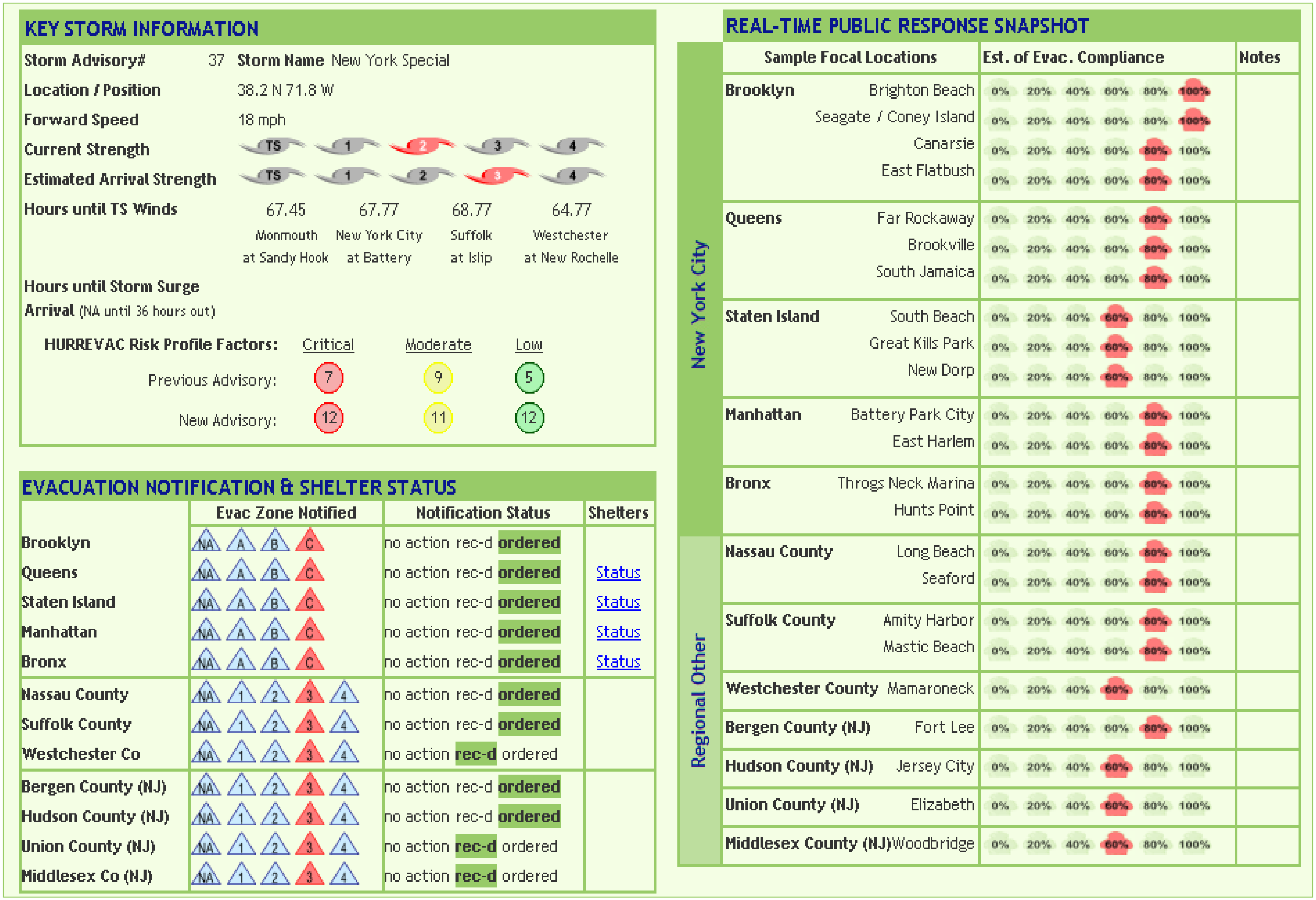

Figure 13: Prototype Dashboard

	CRITICAL INTERREGIONAL TRANSPORTATION FACILITIES STATUS							
	Facility	Owner	Mode	Evacuation Direction	Travel Congestion	Closure Condition	Time Until Closure (Hours)	
WB Towards NJ	Goethals Bridge at center span	PANYNJ	Road	wb	light moderate **heavy** severe	wind	closed	18+
	Outerbridge Crossing at center span	PANYNJ	Road	wb	light moderate **heavy** severe	wind	closed	18+
	Holland Tunnel	PANYNJ	Road	wb	light moderate heavy **severe**	surge	closed	18+
	Lincoln Tunnel	PANYNJ	Road	wb	light moderate heavy **severe**	surge	closed	15
	George Washington Bridge at center span	PANYNJ	Road	wb	light moderate heavy **severe**	wind	closed	18+
	Pulaski Skyway at Hackensack River center span	NJDOT	Road	wb	light moderate **heavy** severe	wind	closed	9
	Verrazano-Narrows Bridge at center span	MTA BT	Road	wb	light moderate **heavy** severe	wind	closed	18+
	Queens Midtown Tunnel	MTA BT	Road	wb	light moderate heavy **severe**	surge	closed	18+
	Brooklyn Battery Tunnel	MTA BT	Road	wb	light moderate heavy **severe**	surge	closed	9
	PATH Tunnels	PANYNJ	Rail	wb	light moderate **heavy** severe	surge	closed	18+
	Penn Station North Hudson River Tunnel	AMTRAK	Rail	wb	light moderate **heavy** severe	surge	closed	14
NB Towards Westchester / CT	Throgs Neck Bridge at approach	MTA BT	Road	nb	light moderate **heavy** severe	surge	closed	15
	Bronx Whitestone Bridge at center span	MTA BT	Road	nb	light moderate heavy **severe**	wind	closed	16
	Hudson Line at Croton Harmon Station	MTA MNR	Rail	nb	light moderate **heavy** severe	surge	closed	14
	New Haven Line at Fairfield Station	MTA MNR	Rail	nb	light moderate **heavy** severe	surge	closed	18+
	Henry Hudson Bridge at center span	MTA BT	Road	nb	light moderate **heavy** severe	wind	closed	12
	FDR sb at 127th Street	NYSDOT11	Road	nb	light moderate **heavy** severe	surge	closed	13
	Major Deegan nb at 230th Street	NYSDOT11	Road	nb	light moderate **heavy** severe	surge	closed	13
	I-95 at Exit 17, Chatsworth Avenue	NYSTA	Road	nb	light **moderate** heavy severe	surge	closed	12
	Hutchinson River Pkwy at Exit 5, Orchard Beach Rd	NYSDOT11	Road	nb	light moderate heavy **severe**	surge	closed	18+
	Lexington Ave Tunnel (4, 5, 6 lines) at 131st St	MTA NYCT	Rail	nb	light moderate **heavy** severe	surge	closed	18+
	Harlem River Tunnel (2, 3 lines) at Harlem River Dr	MTA NYCT	Rail	nb	light **moderate** heavy severe	surge	closed	14
Airports	JFK Airport	PANYNJ	Air	out	light moderate **heavy** severe	surge	closed	9
	LaGuardia Airport	PANYNJ	Air	out	light moderate **heavy** severe	surge	closed	9
	Newark Airport	PANYNJ	Air	out	light **moderate** heavy severe	surge	closed	11
	Teterboro Airport	PANYNJ	Air	out	light **moderate** heavy severe	surge	closed	11
NB from Atlantic Shore	Belt Pkwy wb at Flatbush Avenue	NYSDOT11	Road	nb	light moderate heavy **severe**	surge	closed	18+
	Marine Parkway Bridge at approach	MTA BT	Road	nb	light moderate heavy **severe**	surge	closed	18+
	Cross Bay Bridge at approach	MTA BT	Road	nb	light moderate **heavy** severe	surge	closed	18+
	Atlantic Beach Bridge at approach	NACOBA	Road	nb	light **moderate** heavy severe	surge	closed	18+
	Van Wyck Expy at Grand Central Pkwy	NYSDOT11	Road	nb	light moderate **heavy** severe	surge	closed	9
	Fire Island Ferries	LI Ferry	Port	nb	light moderate heavy **severe**	wind	closed	9
	Long Beach Branch at Long Beach Station	MTA LIRR	Rail	wb	light moderate heavy **severe**	surge	closed	18+
	Broad Channel Station (A line) Jamaica Bay X-ing	MTA NYCT	Rail	nb	light moderate **heavy** severe	surge	closed	9
	Staten Island Ferry	NYCDOT	Port	out	light moderate **heavy** severe	surge	closed	18+

Figure 13: Prototype Dashboard (continued)

7.3 Key Storm Information Module

This module provides current and projected conditions and captures critical storm parameters provided by the NHC advisories and Hurrevac2010 risk profile module provided in real-time. Specifically, this module includes:

- *Storm Advisory #* – The advisory number assigned by the NHC to a specific tropical system. Advisories typically are issued every 6 hours but may be more frequent (every 3 hours) as the storm gets within a 24 hour landfall window.
- *Storm Name* – The name of the storm assigned by the NHC to a specific tropical system from a year by year pre-established alphabetized list of names.
- *Location/Position* – The current location/position expressed in latitude, longitude, and mileage reference from specific cities and landmarks.
- *Forward Speed* – The current forward speed of the storm expressed in miles per hour by direction. This feature is critical to monitor for the Metro New York region as storms in the mid to northern Atlantic tend to increase in forward speed dramatically.
- *Current Strength* – Current intensity based on the Saffir-Simpson Hurricane Wind Scale (SS Scale) with tropical storm as the least intense and Category 4 as the most intense. Category 5 storms are deemed to be meteorologically impossible to sustain in the New York region due to cooler water temperatures.
- *Estimated Arrival Strength* – Projected intensity at landfall or nearest approach of the approaching storm based on NHC forecasts.
- *Hours Until Tropical Storm Winds* – Hours from the current storm location until the arrival of sustained tropical storm winds at one of four pre-selected geographically dispersed locations. Two locations, Monmouth County (NJ) at Sandy Hook and New York City at the Battery, correspond to NOAA tidal gauge locations. The other two locations, Suffolk at Islip and Westchester at New Rochelle are not tidal gauge locations but were discussed by stakeholders and approved by the NWS as being representative of varying arrival conditions of storm hazards within region. The wind arrival times are accessible in HURREVAC in the county specific wind timing reports.
- *Hours Until Arrival of Storm Surge* – Hours from the current storm location until the arrival of surge inundation at one of four pre-selected geographically dispersed locations in the region based on NHC SLOSH projections. The surge arrival time at each location is accessible through the SLOSH display program.
- *Summary of HURREVAC Risk Profile Conditions* – A summary of the number of critical, moderate, and low risk profile conditions from the previous and new/current advisory so that decision makers can see the trend in storm threat to the region. A hyperlink is provided for the user to manually enter the risk profile criteria and conditions for dashboard users to better understand this summary. (Please see Section *6.0 HURREVAC*

Risk Profile Module of the TDR for more information about the risk profile and scored indicators).

One of the many benefits of the Key Storm Information module is the assurance that agency leaders are making the same assumptions about current and expected conditions rather than multiple, and potentially conflicting, weather forecasts.

It is expected that in future phases of the development of the overall dashboard, the Key Storm Information module would automatically populate the data from Hurrevac2010 after every advisory.

7.4 Evacuation Notification and Shelter Status Module

This module focuses on what evacuations, if any, are currently being conducted and the status of available shelters. Each borough and county in the region has an evacuation zone map that is based on storm surge mapping conducted from 2003 through 2005. New York City identifies three distinct levels of evacuation (A, B, and C). For a direct hit, Scenario A corresponds to Category 1, Scenario B to Category 2, and Scenario C to Category 3 or 4 hurricanes. Nassau and Suffolk Counties have four distinct levels of evacuation tied to the four categories of hurricanes. Westchester County, due to its topography and location, has one surge evacuation zone. The module allows staff to show agency executives the level of evacuation being conducted in each borough and county.

In addition to the level of evacuation, the type of evacuation advisory by jurisdiction is also included. The type of evacuation advisory may be “recommended” or “ordered” depending on the certainty and severity of the threat. This may change over time as more (or less) confidence in the forecast is ascertained from the NHC and the local NOAA-NWS office. A “no action” option is also indicated, meaning no areas have been asked to relocate.

A final part of this module includes a shelter status feature in which users enter information, by jurisdiction, on how many evacuation centers and shelters are opened, and how many evacuees are being sheltered. New York City can refer to its SAHANA software program for this information. Other jurisdictions will need to speak with their designated Sheltering Coordinator, whether that is American Red Cross (ARC) or another human service organization. Procedures and protocol would need to be developed for obtaining this data for outlying jurisdictions.

Population of this module will require real-time staff input. Since NYCOEM coordinates the evacuation decision with the Mayor for the City as a whole, input for the boroughs’ evacuation status should be straight forward. Obtaining local evacuation advisories for the other jurisdictions particularly the northern New Jersey counties may be slightly more problematic.

Real-time coordination with the New Jersey Office of Emergency Management (NJOEM) and their partner agency, the New Jersey State Police (NJSP), as well as the New York State Office of Emergency Management (NYSOEM)/New York State Division of Homeland Security and Emergency Services (NYSDHSES) should facilitate the collection of evacuation advisory intelligence to populate any gaps. Also, discussions held as a part of the RELT process should assist in obtaining the needed information.

7.5 Real-Time Public Response Snapshot Module

One of the missing elements in managing evacuations around the coastal United States is accurate, real-time intelligence about the level of actual evacuations taking place out of vulnerable areas. Public officials purport to be managing evacuations, but really have little idea about evacuation compliance in real-time. Evacuation management has become a reactionary exercise in observing traffic congestion and then responding. Since the Metro New York region experiences significant traffic congestion daily, simply observing traffic congestion during an evacuation will not provide a clear picture of whether residents are responding appropriately.

In the Metro New York area, the extreme life threatening storm surge vulnerability of various neighborhoods coupled with little hurricane evacuation experience on the part of the public creates concern regarding evacuation compliance. Some residents may fear leaving personal possessions and/or pets which will also negatively influence decisions to evacuate.

This module of the Metro New York Evacuation Dashboard would provide a snapshot of evacuation compliance by borough and county for neighborhoods that are representative of the most surge vulnerable areas of the region. The selected neighborhoods are areas that were identified in the *New York State Hurricane Evacuation Restudy TDR* (2009) as having a combination of significant storm surge vulnerability and limited access to mass transit facilities. The areas were also highlighted in an evacuation mass transit needs index analysis for New York City; performed during the *New York State Hurricane Evacuation Restudy TDR* (2009). A 'Notes' hyperlink is provided so that any anecdotal observations could be input in real-time.

A future dashboard development phase would be needed to explore methods for populating the real-time public response information for this module. Methods that could be explored include:

- Police "door to door" sampling of evacuation compliance,
- Monitoring of mass cell phone movements (similar to tested protocol in Hurricane Gustav),
- Public electricity/natural gas usage normal versus pre-storm for selected areas,
- Public water usage normal versus pre-storm for selected area,
- Miscellaneous private partner intel, and

- Public transit and surface highway traffic count real-time intel.

Each method will have various advantages and disadvantages regarding implementation and differing levels of effectiveness for gauging real-time public response. New York City would be a national leader for the rest of the coastal United States in obtaining real-time public response data once methods are researched and a preferred method selected.

7.6 Critical Interregional Transportation Facilities Status Module

The final and most important module in the prototype dashboard product is a sheet that is designed to show NYCOEM and agency executives the real-time status of a select and representative sample of the most critical inter-jurisdictional or inter-agency transportation facilities. These facilities are critical to overall regional evacuation movements and by virtue of their location, function, and vulnerability require coordination for determining when regional evacuation operations would cease. Four groups of facilities are provided including:

1. Roadway, bridge, and transit facilities primarily serving westbound movements toward New Jersey
2. Roadway and rail lines primarily servicing northbound movements toward Westchester County and Connecticut
3. Regional airports which visitors and commuters would use to leave/enter the region
4. Roadway, bridge, and transit facilities serving northbound movements away from the Atlantic shore surge areas

Since the overall critical facilities component of the Metro NY Evacuation Project included hundreds of facilities, the list shown on the dashboard is meant to serve as a representative subset of transportation facility data available. While there are undoubtedly other facilities that could be included as indicators of general risk, it was a project imperative to keep the hard copy prototype to a one-page document for ease of use. A larger list is included in the facility tool to Hurrevac2010 and the complete list is included in this TDR. The facilities in this prototype may or may not map to a single entry in Master Facilities List, but to multiple entries for the same facility.

A column is provided showing the primary owner/operator of the dashboard listed facility. The list of owners covers the primary transit operators such as MTA NYCT, MTA LIRR, MTA MNR, PANYNJ, and AMTRAK. The list also includes bridge and surface highway operators such as NYSDOT regions, NYCDOT, MTA BT, and the PANYNJ. A colorized mode symbol indicating whether the facility is road, rail, air, or port/marine is placed beside each facility and owner entry.

The next column of information in this module would allow for staff of each owning agency to indicate the current congestion level of the facility. Choices are light, moderate, heavy, and severe with the selection highlighted by a green, yellow, red, or black background respectively. While each agency may decide to develop quantitative measures to trigger the selection of each congestion level, this feature of the prototype dashboard is intended to be a qualitative judgment on the part of agency staff receiving information directly from the field. It is expected that as NYCOEM and agency executives participate in RELT calls, agencies would be prepared to discuss how their facilities with heavy or severe congestion indicators are impacting evacuation movements. Future dashboard developmental phases may include tasks to work with agencies on defining congestion measurements.

The dashboard includes a column which indicates the primary coastal storm hazard which would close a particular facility entry. If the indicator is surge, then the assumption is that storm surge flooding before eye landfall would close the facility due to the facility's physical characteristics. An example would be a tunnel facility which would be compromised by the intrusion of surge flooding based on low lying system entry points identified in the facilities portion of the project. If the indicator is wind, then the assumption is that the early arrival of sustained tropical storm winds would shut down the facility. An example would be a high-level bridge which would receive tropical storm winds well before the arrival of tropical storm winds at ground level.

The final feature of this module and the dashboard is a sliding scale that would indicate the number of hours left until the facility must close based on current expectations of storm strength and forward speed. Since Hurrevac2010 interprets the NHC advisory data and couples it with facility vulnerability information developed in this project, the data could be imported manually in the current dashboard version or electronically in future versions. Of critical importance to executive level discussions is the recognition of which key facilities will close first and the impacts that should be reflected in real-time public messages and operational responses. Each storm event, depending on intensity and track, will trigger different sets of issues and closure timelines. Updating the dashboard after each advisory and/or significant agency action would be essential to informed decision making and situational awareness.

7.7 Electronic Prototype Dashboard

As a part of the current 2010 Metro NY Evacuation Project, the hard copy version of the dashboard was converted into an electronic format to give project participants an initial feel for how the dashboard could function. A time and date stamp was incorporated into the footer of the dashboard to show how a historical record could be maintained throughout the pre-storm use of the dashboard after each advisory. The hard copy was originally developed in Microsoft Publisher and an electronic version was developed using Coldfusion8 and MySql server. While

NYCOEM may elect to further develop the product before utilizing it in a real event, the prototype electronic version will help NYCOEM generate internal operating protocols for its use.

8.0 Regional Emergency Liaison Team (RELT) Plan

The RELT is an interagency conference call comprised of federal, state, local and non-governmental organizations with involvement in supporting regional evacuations in the New York metropolitan region. The intent of the RELT is to promote better and more consistent communications and coordination between multiple agencies and to support executive level decision makers in implementing evacuations. A component of the Metro NY Evacuation Project involved developing a plan to guide the activities of participating RELT agencies in planning for and implementing a regional evacuation. The concept and use of RELT is an evolving concept in the region, therefore, this deliverable was completed with the status of *working draft.*

8.1 RELT Plan Development

The RELT plan development process incorporated a review of existing related documents and the findings from the transportation facilities analysis to develop the RELT plan and supporting executive and operational level decision making checklists. Source materials were provided by NYCOEM for review in November 2009. Documents reviewed as part of this process included:

- *City of New York Coastal Storm Plan – Decision Making Playbook*, NYCOEM (2007)
- *City of New York Coastal Storm Plan – Evacuation Plan*, NYCOEM (2007)
- *RELT Protocols*, New York Urban Area Working Group – Draft (2009)
- *RELT Workshop, After Action Report,* NYCOEM (2009)
- *RELT Operations Conference call procedures* (one page form), NYCOEM (2009)
- *Regional Evacuation Plan – Regional Playbook,* Regional Catastrophic Planning Group – Draft (2010) [obtained in March 2010]

Close coordination was maintained with NYCOEM during the fulfillment of this task. In addition to regular conference calls with NYCOEM, various formal and informal meetings were held to introduce stakeholders to the RELT plan development concept, ensure the fulfillment of NYCOEM planning objectives, and guide the completion of this task. The key meetings included:

- December 14, 2009 – Presented at the stakeholder Kick-Off Meeting. All stakeholders were introduced to the RELT plan development task, as included in the USACE-NAP Scope of Work, (dated November 16, 2009).
- February 18, 2010 – A RELT expansion discussion conference call was held with key project team staff [New York-New Jersey-Connecticut-Pennsylvania Regional Catastrophic Planning Team (NY-NJ-CT-PA RCPT) and NYCOEM] to review and document the NYCOEM intentions for the project.

- March 5, 2009 – Stakeholders were provided a progress update, including a review of the preliminary draft of the basic RELT plan. Discussion on the checklist development process and potential content and format of the checklists was covered.
- March 9, 2010 – Briefed the Regional Catastrophic Evacuation Plan – Steering Committee via conference call on the RELT plan and received feedback / input for recommended plan content.
- April 14, 2010 – Met with NYCOEM staff to review revisions to the draft RELT checklists. Discussed approaches for restructuring.
- July 6, 2010 – Participated in meeting with NYCOEM staff to review materials developed for the RELT facilitated discussion workshop and to discuss review comments on the draft RELT plan.
- July 14, 2010 – Conducted a half-day RELT stakeholder workshop to elicit input into the RELT plan. Stakeholders were provided with a hypothetical storm scenario and a list of general assumptions and discussion topics for each emergency phase (planning, mobilization, evacuation, and the pre-zero / zero hour phases). Participants discussed key agency or and functional group actions, expected interdependencies, facilities of concern and anticipated resource needs at each phase. Presentation materials, including the Power Point and participant handout, are included in Appendices W and X.

8.2 RELT Plan Overview

Draft documents were prepared for review and comment during the project, including the RELT plan and the checklists. During the document review process, the outline and content guidance was adjusted to limit background information and hazards and consequence analysis to focus more on developing the evacuation phase-based plan checklists. The RELT document went through several iterations based on feedback from the facilitated stakeholder workshop and comments received from NYCOEM. A final draft plan document was delivered recognizing the unique ‘work in progress’ status of the RELT.

The structure of the final draft RELT plan includes an executive summary, and two main plan sections; an Introduction that provided a background on the RELT and its membership, and a Regional Concept of Operations section that covered how the RELT would be implemented. Supporting sections of the plan included conference call guidelines, a RELT organizational chart, event phase description charts for notice and no-notice events as well as the RELT executive and operational level decision making checklists and conference call agendas. The final draft plan (dated December 22, 2010) is included in Appendix Y.

8.3 Decision Checklists

An essential part of the project involved developing the RELT executive and operational level decision making checklists. The RELT is comprised of two groups of stakeholders. The executive level checklists were developed for the RELT Tier 1 group, which is focused on strategic level issues and coordinates executive decision-making and information sharing between the region's emergency management agency leadership. Participating agencies are listed below:

- NYCOEM,
- NYSOEM,
- Nassau County Office of Emergency Management (Nassau OEM),
- Suffolk County Department of Fire Rescue and Emergency Services (Suffolk FRES), and
- Westchester County Department of Emergency Services (Westchester DES).

The RELT Tier 1 group may be expanded to include other neighboring jurisdictions as needed.

The second group, Tier 2, is focused on operational level issues and serves as a mechanism to coordinate efficient, timely evacuations and to identify and discuss incident action objectives. This group includes the five Metro Area emergency management agencies as well as five other key regional operations members. The ten participant agencies include:

- NYCOEM,
- NYSOEM,
- Nassau OEM,
- Suffolk OEM,
- Westchester DES,
- City of Yonkers OEM,
- MTA Headquarters,
- PANYNJ OEM,
- NJOEM, and
- New Jersey Office of Homeland Security and Preparedness (NJOHSP).

These agencies will always be represented when the Tier 2 group is activated. The Tier 2 group may be expanded to include additional elective agencies that are expected to have direct operational roles in directing or supporting regional evacuations based on the needs generated by the incident. These agencies may be organized functionally into the following four subdivisions:

- Roads and Bridges,
- Public Transportation,
- Public Safety, and
- Waterways.

Just as with the total number of Tier 2 elective agencies, additional functional grouping may be established, as required, if the Tier 1 group feels that this will help better coordinate evacuation operations.

The checklists developed for each RELT Tier were designed to serve as call agendas or guides and included the key prompts that might need to be considered by the members of the Tier group during specific phases of an evacuation. The checklists covered the five evacuation phases; Planning (96 – 72 hours before zero hour), Mobilization (72 – 48 hours before zero hour), Evacuation (48 – 0 hours before zero hour), Pre-Zero Hour (24 – 0 hours before zero hour), Zero Hour (covering the final agency shut down times / concurrent with hazard arrival time), Post Incident Phase (0 – 7 days after the incident). Both sets of checklists included a standardized conference call record form.

9.0 Conclusions and Recommendations

While the development of the products and data presented in this TDR is a major step forward for the region's storm preparedness, there is still a great deal that could be done to advance the preparedness of the transportation agencies in the region. The region's unique and severe vulnerability to storm surge and winds associated with coastal storms cannot be overstated. The region has been impacted historically by major hurricanes but one has not hit in recent history with the levels of population and infrastructure that are now in place. Many residents and businesses while "street smart" regarding every day urban issues, are inexperienced in dealing with the direct impacts of a major storm event.

It is recommended that the following be considered in future evacuation planning efforts for the city and region:

Modeling:

- Rate of rise is a significant issue affecting the surge vulnerability of transportation facilities. No hydrograph or time history information was provided by NOAA-NWS for the project. NOAA-NWS was also unable to provide the level of local interaction and support afforded the *Metro New York Hurricane Transportation Study TDR* (1995) in regards to SLOSH education. A request by NYCOEM to NOAA-NWS should be made for additional surge analyses study validation and public outreach.

- The effect of wind as a pre-landfall hazard is significant, particularly in relation to high span bridges. Additional research on wind modeling may be beneficial to refining the wind-related pre-landfall assumptions.

Mitigation:

- Each agency should carefully review the list of facility locations in the Master Facilities List provided in this project to see if any physical mitigation projects could be accomplished that would offer affordable system protection from surge entry. Saltwater intrusion into underground facilities is potentially very damaging economically.

- Agencies should review capital improvement plans to identify whether facilities included in the study are scheduled for construction (modification or expansion). The potential evacuation timing benefits of these improvements should be considered.

Preparedness:

- Recent disaster events have shown that large numbers of people tend to arrive at airport facilities and offer transportation hubs with sheltering needs (food, water, law enforcement, etc). Airports and major transit depots need to anticipate these human impacts and plan for this likelihood.
- NYCOEM does a commendable job of providing HURREVAC training to its constituents. The new risk profile and updated critical facilities tools modules and training material need to be incorporated into all future HURREAVAC trainings with regional stakeholder agencies.
- To ensure the accuracy of data included in HURREVAC tools, stakeholder agencies should review the Master Facilities List on an annual basis. A process should be established to allow NYCOEM to coordinate the integration of changes into the existing data set.

Operations:

- Despite advances in intelligent transportation systems (ITS) for traffic management, real-time monitoring of evacuation progress still needs to be developed more fully nationally. Systems for monitoring evacuation compliance should be explored, whether monitored based on traffic monitoring (traditional or based on cell phone locations) or utility usage data.
- Whether the prototype dashboard offers decision makers a user-friendly framework for reviewing information on storm and evacuation status, opportunities exist to more fully automate the data collection/integration aspect of this feature. NYCOEM should explore methods for standardizing or automating the dashboard data collection process.